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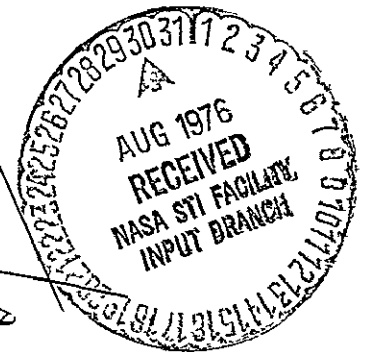
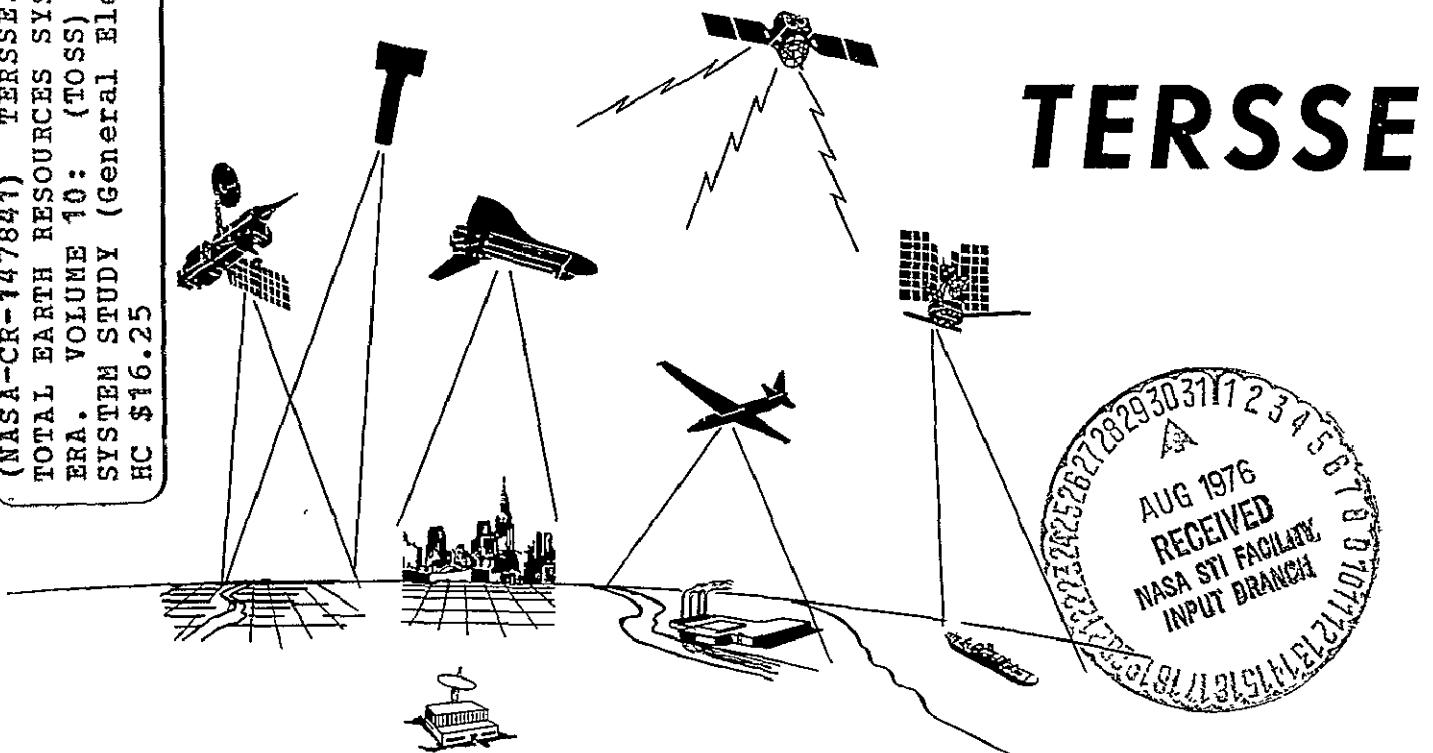
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# TOTAL EARTH RESOURCES SYSTEM

## FOR THE SHUTTLE ERA

### VOLUME 10 TOSS—TERSSE OPERATIONAL SYSTEMS STUDY



GENERAL  ELECTRIC  
SPACE DIVISION

DECEMBER 1975

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DRL NO. T-880 (MA-129TA)

## TERSSE

DEFINITION OF THE  
TOTAL EARTH RESOURCES SYSTEM  
FOR THE  
SHUTTLE ERA

### VOLUME 10 TOSS - TERSSE OPERATIONAL SYSTEM STUDY

PREPARED FOR  
EARTH RESOURCES PROGRAM OFFICE  
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
JOHNSON SPACE CENTER  
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## PREFACE

The pressing need to survey and manage the earth's resources and environment, to better understand remotely sensible phenomena, to continue technological development, and to improve management systems are all elements of a future Earth Resources System. The Space Shuttle brings a new capability to Earth Resources Survey including direct observation by experienced earth scientists, quick reaction capability, spaceborne facilities for experimentation and sensor evaluation, and more effective means for launching and servicing long mission life space systems.

This study, entitled TERSSE, Total Earth Resources System for the Shuttle Era, was established to investigate the form of this future Earth Resources System. Most of the constituent system elements of the future ER system and the key issues which concern the future ER program are both complex and interrelated in nature. The purpose of this study has been to investigate these items in the context of the total system utilizing a rigorous, comprehensive, systems oriented methodology.

Of key concern to the Earth Resources Program's the nature and economic benefits of an operational system. The transition to operational use of this technology is the major current challenge. By combining economic analysis with system design, this study has investigated the form of the initial operational system.

The results of this study are reported in ten separate volumes; their titles are:

Volume 1 Earth Resources Program Scope and Information Needs

Volume 2 An Assessment of the Current State-of-the-Art

Volume 3 Mission and System Requirements for the Total Earth Resources System

Volume 4 The Role of the Shuttle in the Earth Resources Program

Volume 5 Detailed System Requirements: Two Case Studies

Volume 6 An Early Shuttle Pallet Concept for the Earth Resources Program

Volume 7 User Models: A System Assessment

Volume 8 User's Mission and System Requirement Data

Volume 9 Earth Resources Shuttle Applications

Volume 10 TOSS - TERSSE Operational System Study

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**SECTION 1**  
**INTRODUCTION AND SUMMARY**

## SECTION 1

### INTRODUCTION AND SUMMARY

#### 1.1 INTRODUCTION

In the past few years notable progress has been made in the technical capabilities of the Earth Resource Program. The second Landsat has been successfully operated, with its companion, for over 1 1/2 years in support of hundreds of experimental investigations. The Landsat data processing system has progressed in its capabilities to satisfy many needs of the users. And the applications themselves have reached the mature demonstration stage in several instances, the most notable of which is the Large Area Crop Inventory Experiment (LACIE).

During this same time frame two major study efforts have been underway. ECON has conducted economic benefits studies which show the existence of considerable economic promise for the application of remote sensing to resource management. And General Electric has conducted the Total Earth Resources for the Shuttle Era (TERSSE) study to outline the structure and development of future systems.

This report deals with a combination of the foregoing two efforts, along with the experience from Landsat and LACIE, to define the system performance and economics of an operational Earth Resources system. The system is to be based on current (Landsat follow-on) technology and its application to high-priority resource management missions, such as global crop inventory. The TERSSE Operational System Study (TOSS) investigated system-level design alternatives using economic performance as the evaluation criterion. As such, the TOSS effort represented a significant step forward in the systems engineering and economic analysis of Earth Resources programs. By parametrically relating engineering design parameters, such as sensor performance details, to the economic benefit mechanisms a new level of confidence in the conclusions concerning the implementation of such systems can be reached.

#### 1.2 STUDY GOALS AND OBJECTIVES

The objective of the TOSS effort was to analyze and define the remote sensing system necessary to capture the economic benefits identified for several high priority Earth Resources application missions. The study approach was to combine the engineering and systems analysis represented by TERSSE with the economic benefit analysis represented by the ECON work into a coherent and integrated result.

The three major questions addressed by TOSS in response to the overall objective were:

- (1) What is the economic benefit of a Thematic Mapperbased operational system?
- (2) What is the system configuration?
- (3) How can system design be based on economic criteria?

The answer to each of these questions along with the underlying analysis and supporting data are the focus of this report.

In responding to the study objectives the TOSS team was faced with a complex, interrelated, and multifaceted problem. Ancillary but necessary questions and specific but secondary issues arose which had to be dealt with. Many of these had been approached in the past by the study team and others, but for the most part, the information available was not in the form suitable nor in degree precise enough for the direct application in TOSS. Most importantly, these questions and issues had never been interrelated and addressed simultaneously as part of a single large problem.

The first step in designing a system is to formulate user requirements which define the information needs of the operational resource manager. Understanding the user and his needs requires an analysis of the economic benefit mechanism, the actual processes by which new or improved information will have value. Part of the approach taken in TOSS was to define the complete information flow process, the step-by-step transfer and transformation of data and information as it related to the particular user.

The development of system requirements which are responsive to the wheat inventory user needs necessitated a comprehensive analysis and design of a stratified sampling plan. This sampling plan together with its interactions with the impact of cloud cover dictated the acquisition system configuration in terms of the number of spacecraft and their orbital coverage requirements. The system configuration was also influenced by the understanding and utilization of TDRSS and DOMSAT's as data relay elements.

The development of the system performance required an error analysis which analyzed and combined several different error components. The tradeoff between accuracy and timeliness was necessary as part of integrating the engineering and economic results. Throughout the study, issues such as the effect of field size distribution on the choice of classification technique had to be addressed in an end-to-end analysis that led to the expected system benefit.

### 1.3 CONCLUSIONS AND RECOMMENDATIONS

The major conclusion of TOSS is that an operational remote sensing Crop Inventory System containing a Thematic Mapper generates very sizeable economic benefits to the United States and therefore should be implemented. The size of the long term benefits to the U.S. of operating such a system for the global inventory of wheat is computed as \$ 428.8 million dollars per year. This estimate was made using rigorous analysis and conservative assumptions. Note that these benefits accrue from a single application mission (although admittedly the most promising); additional benefits may be expected as capability to serve other missions is added.



The improvements in system performance promised by using the Thematic Mapper as the acquisition sensor, instead of the Multispectral Scanner, are considerable. Its combination of improved spatial and spectral coverage will generally reduce the system error by over half, all other system characteristics being the same. This improved performance can be economically quantified as an incremental benefit to the U. S. of \$ 37.6 million dollars per year. The value of this incremental benefit stream exceeds the corresponding cost stream by a factor of four or five; that is the Thematic Mapper is worth four to five times its cost for this one mission, with one crop alone. The development of the Thematic Mapper should be continued.

The implementation of the Crop Inventory System using Landsat follow-on technology will provide significant increases in performance in three major areas, each of which is a major benefit-producer: sensor performance, sample size, and system timeliness. It has decreased the sensor LFOV from 80 to approximately 30 meters; no major additional decrease of a similar size would be economically warranted (by the crop inventory missions studied). Similarly, it has increased the sample size from 5,000 (LACIE) to 50,000 and decreased the system timelag to 12.5 days; further major increases in performance of similar magnitudes would not produce major benefit increases of comparable size.

In summary, the Thematic Mapper based system outlined herein represents the technologically-achievable economic "knee of the curve", in a performance sense.

Foremost of the study recommendations is that the Crop Inventory System should be aggressively pursued and operationally implemented. The size of the economic benefits to the United States approach one half billion dollars per year. Even if in spite of the careful analysis, both technical and economic, these benefits should turn out to be overstated, the magnitude of the benefits from just this one application mission demand that an operational remote sensing system be implemented. Although further analysis and experimentation are still required, the current indications are so positive that the move towards an operational system must be continued with all reasonable speed.

Due to the many similarities in the requirements of different missions it is not only feasible but desirable that the basic Crop Inventory System be expanded to provide service to other related missions. Care must be taken that this expansion to other missions is not allowed to overly dilute or diminish the primary mission performance. Nevertheless, there are several closely related applications which could be served with only minor changes to the design. For example, extension to the survey and inventory of other agricultural crops is straight forward. Other inventory applications in the areas of land and forest management should also be investigated for compatibility.

In order to achieve the required levels of system performance, the system should take maximum advantage of recent technological improvements. Signal among these is the choice of the new Thematic Mapper sensor over the decade older Multispectral Scanner sensor. The performance increment estimated for the TM just for the wheat mission more than covers the required TM development costs. Other technology improvements such as TDRSS, DOMSAT's, and high speed processors need to be utilized as well to fully capture the potential benefits.

The system implementation approach developed in TOSS uncovered several technology areas where additional research and development is required. Although the fundamentals are mostly understood and research results are available, development effort is required in the area of extractive processing algorithms and their implementation in order to refine them for operational use.

Speed and cost are of prime importance in the transition from experimental use to operational system design. The TOSS system design for the extractive processing function requires the use of a multiple terminal interactive processor. Although the concept for multiple terminal systems is not new, significant development is required in order to realize an efficient multi-terminal processing system. For example, the specific type of ancillary data required by an operator needs to be defined and the best method for making it available to him needs analysis. Another issue is, how many operators can simultaneously share the same central processing hardware?

A third area requiring further development is the process and mechanization of multiple integrated data bases. The USDA/SRS data base of ground truth and ancillary data needs to be interfaced with the extractive processing spectral data base; and both of these need to interface with a data base of historical data on crop production forecasts. The architecture and technology for interfacing these multiple multi-source data bases should be further developed. Issues such as access protocol, data security, indexing structure, etc. need to be analysed and resolved.

#### 1.4 STUDY BACKGROUND AND PARTICIPANTS

There are three categories of activity which form the foundation and background for TOSS. First, the economic benefit studies performed by ECON Incorporated during 1974 and 1975 quantify the economic benefits to the United States from the application of improved information to various Earth Resource Survey (ERS) applications. The 1974 work consisted of a broad overview approach to many of the ERS missions while the 1975 work focused in-depth on four particular missions; both efforts are understood and accepted by NASA and the OMB. The four case studies analyzed in depth are: (1) U. S. Crop Survey; (2) Global Crop Survey; (3) Rangeland Management; and (4) Inland Water Management.

The second category consists of the several studies and design efforts which together define the near term improvements possible and probable for the remote sensing system. These efforts include the Purdue Thematic Mapper Requirements Review, the EOS Phase B Design Studies, the TERSSE study, and the various Thematic Mapper Point Designs. Collectively, these efforts define the technology improvements, particularly in the sensor area, which can be applied to a near future system. Of these, the Purdue Thematic Mapper Review is the most significant to TOSS in that it represents the sensor technology baseline to which the TOSS analysis was applied. The previous TERSSE study activity provided the understanding and perception upon which to base the total end-to-end system view and approach.

The third background category is that of the experimental research results obtained from Landsat data. Included here are the LACIE activity, the CITARS results, and the hundreds of experiments conducted by Principal Investigators as part of the Landsat 1 and 2 program. These experiments provide empirical benchmarks to which predicted analytical capabilities can be related. Of particular importance is the LACIE (Large Area Crop Inventory Experiment) effort which represents the largest and most significant application of Landsat data to date. The LACIE is the most nearly operational (in terms of its scope and timing requirements) effort yet for a wheat inventory application; as such, its character and results are unique.

The TERSSE study was established as a systems oriented, top-down study to investigate the form of the near future Earth Resources System. The constituent system elements of the future ER system and the key issues which concern the future ER Program are both complex and interrelated in nature. The purpose of TERSSE has been to investigate these items in the context of the total system utilizing a comprehensive, systems oriented methodology. The TOSS activity was performed as part of this ongoing TERSSE study effort.

ECON Incorporated has an economic benefit study contract (NASW 2558) with NASA Headquarters (OA) to provide NASA with an analysis and overview of the economic benefits available to the United States of a space-based Earth Resources Survey program. As part of this effort ECON has performed detailed case study analyses of four specific application missions. These four are: (1) U.S. Crop Survey; (2) Global Crop Survey, (3) Rangeland Management; and (4) Inland Water Management. ECON participated as a subcontractor to General Electric on TOSS in order to infuse the study with their economic expertise and to interpret the results of their econometric models.

The TOSS study was performed for the Earth Resources Program Office, ERPO, at the Johnson Space Center by the General Electric Space Division supported by ECON Incorporated under subcontract to General Electric.

Although no formal relationship existed between the study team and the USDA, several meetings and discussions were held with USDA personnel on an informal basis. To assist the TOSS study in maintaining an independent approach as well as to minimize any disruptive impact on LACIE, it was decided at the outset that contract with the LACIE program would be kept to a minimum. Throughout the study, the study team received guidance and assistance from NASA personnel at Goddard, Johnson and Headquarters.

## 1.5 ORGANIZATION OF REPORT

This report volume, TERSSE Final Report - Volume 10, is the final report for the TOSS activity of the TERSSE study. This volume is organized into several sections which represent the major activities of the study. The in-depth technical discussion of the various issues and the supporting data are included as appendices. The sections of this report and their contents are:

### Section 1, INTRODUCTION AND SUMMARY

Presents a concise overview of the TOSS study including the background and context within which it was conducted. A major section summarizes the results, conclusions, and recommendations of the TOSS activity.

### Section 2, MISSION REQUIREMENTS

Presents a description of the Earth Resources applications addressed in TOSS and formulates the specific mission requirement against which the system design will be based. The section concentrates on the two agriculture applications and summarizes two others.

### Section 3, SYSTEM ANALYSIS

Presents a comprehensive description of the engineering and technical analysis done in TOSS to establish the complete end-to-end analytical linkage for assessing system performance. Includes discussions of classification accuracy, mensuration accuracy, sampling plans, field size distributions, and system timing.

### Section 4, SYSTEM DESIGN

Presents the TOSS design concept for the Crop Inventory System. Includes a summary of major subsystem elements and the overall system architecture. A significant section shows the use of the TOSS analysis in accomplishing system level design trades with economic benefit as the criteria.

### Section 5, TOSS ECONOMIC ANALYSIS

Presents an overview of the economic study activity done as part of TOSS and also that done prior to TOSS which forms part of the overall foundation upon which TOSS rests.

In addition to the main body of the report considerable material is contained in the seventeen attached appendices. The goal of this report was to provide a complete report, of uniform technical depth, as the main body and to reserve the appendices for greater in-depth discussion of specific technical issues. The appendices and their contents are:

#### Appendix A - US Crop Survey Econometric Mode

detailed derivation and development of ECON's economic model for the U.S. Crop Survey Mission.

#### Appendix B - Economic Loss Associated with the Current USDA Crop Reporting System

in order to ascertain the net economic benefit of a new information system, it is necessary to "baseline" the economic performance of the current system.

#### Appendix C - US Crop Survey Mission

contains a description and discussion of the user needs, decision process, benefit mechanism, information flow, and mission requirements for the US Crop Survey Application mission.

#### Appendix D - Global Crop Survey Mission

contains a description and discussion of the user needs, decision process, benefit mechanism, information flow, and mission requirements for the Global Wheat Survey Application mission.

#### Appendix E - Rangeland Management Mission

contains a description and discussion of the user needs, decision process, benefit mechanism, information flow, and mission requirements for the Rangeland Management application mission.

#### Appendix F - Inland Water Management Mission

contains a description and discussion of the user needs, decision process, benefit mechanism, information flow, and mission requirements for the Inland Water Management application mission.

#### Appendix G - Area Mensuration Accuracy

presents the detailed derivation of the analysis which assesses the system performance capability of locating field boundaries and mensurating the area of fields.

#### Appendix H - Bayesian Classifier Simulation Results

in order to estimate the performance of an extractive processor, a small simulation was developed which accepts inputs on crop signature, sensor characteristics, and classifier parameters.

#### Appendix I - Residual Image Preprocessing Errors

contains an analysis of the error contributions due to the radiometric and geometric preprocessing function.

#### Appendix J - Field Size/Shape Distribution

as part of TOSS it was necessary to determine the distribution of field sizes by country. This appendix contains an extensive collection of field size data.

#### Appendix K - Analysis of Cloud Cover

presents a full discussion of the cloud cover impact assessment analysis done in TOSS. This analysis develops a technique which uses multiple probabilities of various degrees of cloud cover for each location.

#### Appendix L - Crop Maps and Calendars

as part of the mission analysis effort to scope the system loading and determine the sampling plan, an extensive set of crop maps and calendars was compiled for the seven crops of interest.

#### Appendix M - TOSS Statistical Sampling

contains a full development and discussion of the sampling plan and associated errors used in TOSS.

#### Appendix N - Thematic Mapper Characteristics

contains summary material from the Purdue Thematic Mapper Working Group which defines the Thematic Mapper characteristics used in TOSS.

#### Appendix O - Tracking and Data Relay Satellite System (TDRSS)

contains a description of the TDRSS and discusses its utilization by the TOSS spacecraft system.

#### Appendix P - Error Analysis

this appendix presents the mathematical derivation of the performance (error) analysis components that from the backbone of the TOSS system analysis.

#### Appendix Q - Report on: TERSSSE Operational System Study (TOSS) Review

following the final TOSS study briefing a review process was conducted with several groups knowledgeable in agricultural remote sensing. This appendix presents a summary of that review.

## **SECTION 2**

### **MISSION REQUIREMENTS**

## SECTION 2

### MISSION REQUIREMENTS

In order to design a system which will serve an application mission, consideration must first be given to the basic requirements of the mission. The system should be adapted to serve the mission, not vice versa; the fundamental "tops down" approach of TERSSE. At the beginning of the TOSS effort, each of the four application missions: (1) US Crop Survey, (2) Global Crop Survey, (3) Rangeland Management, and (4) Inland Water Management were studied to assess their mission requirements. This section presents a brief summary of the requirements thus derived; a more complete discussion of the requirements for each mission are presented in Appendices C through F for the four missions respectively.

The overall activity of this mission requirements task is shown in Figure 2-1. For each application mission a review of available study reports was made and a user representative familiar with the specific application needs was interviewed. Particular emphasis was placed on understanding the economic benefit mechanism(s) of the application; that is, the particular process which translated resource information into economic value. The result of this activity was a specific set of mission requirements and an information flow diagram, for each application, which would enable the study team to formulate a set of system requirements.

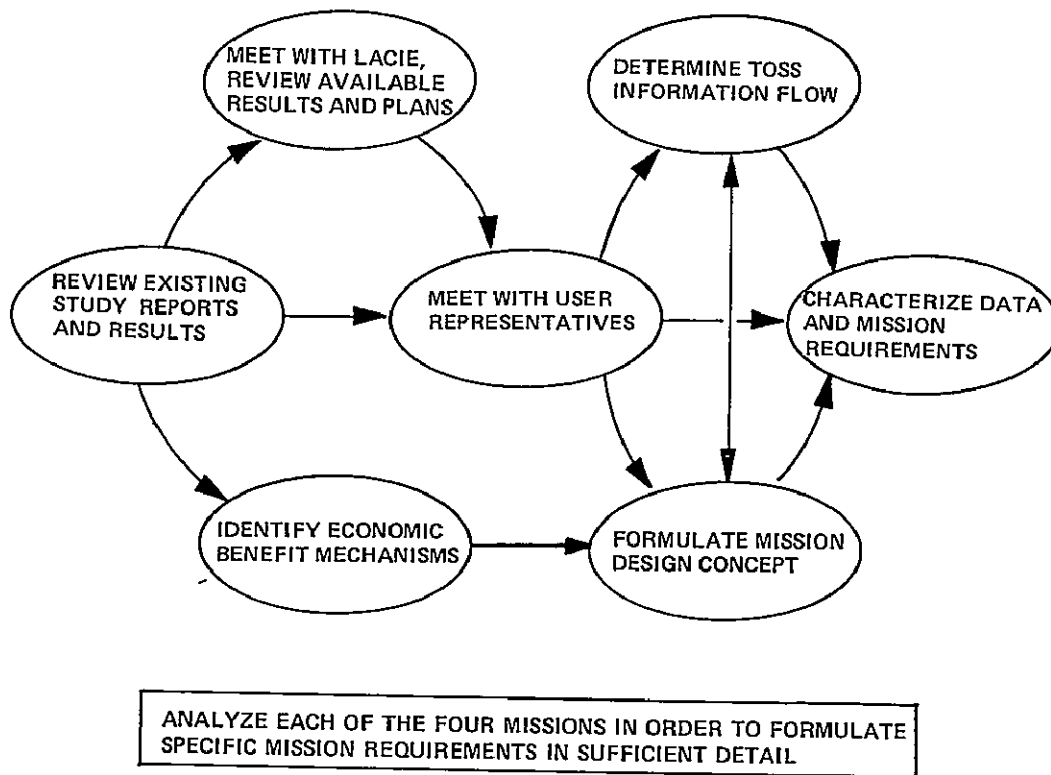


Figure 2-1. Mission Requirements



As previously mentioned, the TOSS study was redirected during its early phases to terminate effort on the Rangeland and Inland Water Management missions and to concentrate in more detail on the two agriculture missions. Thus, although the mission requirements phase was completed for these two missions they were not iterated with the system design concept.

## 2.1 US CROP SURVEY

The objective of the US Crop Survey Mission is to periodically provide a public estimate of the current production of several major US grown crops on a national and state level reporting basis. The ultimate users and beneficiaries of this mission are the producers and consumers of the US who will alter their inventory practices based on improved production estimates.

The TOSS study focussed its estimation of system performance and computation of benefits solely on the wheat crop. However, when the mission is implemented, the system should provide production estimates on several crops in addition to wheat. Although wheat is the single most important crop economically, additional economic benefits can be realized for each crop whose production estimates are improved. Once a basic system is established for the wheat crop the increase in system cost and complexity is relatively minor to provide coverage for additional crops other than wheat.

In order to provide a preliminary group of crops upon which to scope the system design a rudimentary selection process was established. The various possible crops of interest were ranked according to the seven criteria shown in Figure 2-2. The data used for these rankings is for the years 1971 and 1972. The preliminary group of crops began with the five specific crops modeled in the ECON economic work, ECON considered for their US Crop Survey work the crops of Wheat, Soybeans, and Small Grains (an aggregate of wheat, barley, rye, and oats as a single class). Corn and Rice were added to these five, rice because of its importance in the world scene and corn because of its importance in the U.S. It is worth mentioning that the resulting list is by no means exclusive (nor even very rigorous); its purpose is to provide a starting point for considering a global crop system. For the purposes of TOSS then, a list of seven crops were decided upon; these seven are:

- |             |           |
|-------------|-----------|
| 1) Wheat    | 5) Oats   |
| 2) Rice     | 6) Rye    |
| 3) Corn     | 7) Barley |
| 4) Soybeans |           |

<u>U. S. ACREAGE</u>	<u>U. S. PRODUCTION</u>	<u>WORLD ACREAGE</u>	<u>WORLD PRODUCTION</u>
1. CORN	1. CORN	1. WHEAT	1. POTATOES
2. ALL HAY	2. WHEAT	2. RICE	2. WHEAT
3. WHEAT	3. SUGAR CANE	3. MILLET/ SORGHUM	3. RICE
4. SOYBEANS	4. SUGAR BEETS	4. CORN	4. CORN
5. SORGHUM	5. SOYBEANS	5. BARLEY	5. BARLEY
⋮	⋮	⋮	⋮
<u>U. S. FARM VALUE</u>	<u>U. S. EXPORT</u>	<u>TOTAL WORLD TRADE</u>	
1. CORN	1. BARLEY	1. WHEAT	
2. SOYBEANS	2. CORN	2. CORN	
3. HAY	3. MILLETS/ SORGHUM	3. SUGAR	
4. WHEAT	4. OATS	4. RICE	
5. TOBACCO	5. POTATOES	5. BARLEY	
⋮	⋮	⋮	

Figure 2-2. Crop Selection Criteria

The mission requirements resulting from this phase of TOSS for the US Crop Survey Mission are summarized in Figure 2-3. The system output of current production estimates for each of the seven selected crops should be publicly disseminated at a regularly established place and time just as the USDA disseminates similar data today. The frequency of publication should be monthly with consideration given to a bimonthly update cycle. The accuracy goal (if achievable) for the system was established at 97% with a two sigma confidence level. The level of aggregation of the reported production estimates should be at least to the state level (and possibly even to the Crop Reporting District, CRD, level).

## 2.2 GLOBAL CROP SURVEY

The objective of the Global Crop Survey mission is to periodically provide current production estimates of major crops of interest to the United States on a world wide basis. The ultimate beneficiaries of this mission are the US producers and consumers who will benefit from smoother international trade flows. The regular publication of production and production estimate data will benefit not only the US but also foreign countries participating in the international trade market as well. However, this study has restricted itself to addressing only the distribution of such information to the US and the attendant benefits to the US, not the system and benefits to the rest of the world.

UPDATE CYCLE (OUTPUT REPORTS) MONTHLY, RANGE OF 2 WEEKS TO 1 MONTH

TIMELINESS 7 DAYS FROM LAST INPUT, RANGE OF 2 TO 14 DAYS

SYSTEM ACCURACY U S PRODUCTION LEVEL 97% ACCURACY, 95% OF THE TIME

OUTPUT PRODUCT CURRENT PRODUCTION ESTIMATES OF MAJOR U S CROPS VIA STATISTICAL REPORT PUBLICATION

OUTPUT DISTRIBUTION PUBLIC RELEASE AND DISSEMINATION AT FIXED LOCATION AND INTERVALS

AREA OF COVERAGE U S AGRICULTURAL REGIONS

INFORMATION GRID SIZE STATE, POSSIBLY CRD

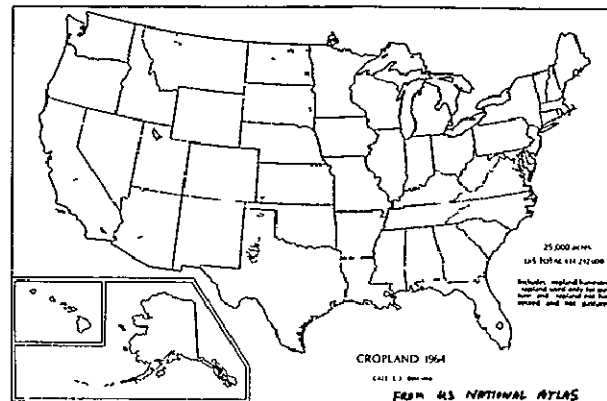


Figure 2-3. Data and Mission Requirements - US Crop Survey

For the TOSS study the analysis effort was constrained exclusively to the single crop of wheat, primarily because this is the only crop for which the economic benefits were estimated (by ECON). As was the case for the US Crop Survey mission, the actual system implemented should provide coverage for all major crops, not just wheat. The same seven crops addressed above for the US Crop Survey mission were considered again as the baseline crop set for the global mission.

The ECON Inc. economic analysis model addressed eleven specific countries in formulating the benefits estimate. These eleven countries are:

- |              |               |
|--------------|---------------|
| 1. USA       | 7. SPAIN      |
| 2. USSR      | 8. FRANCE     |
| 3. UK        | 9. ITALY      |
| 4. CANADA    | 10. INDIA     |
| 5. ARGENTINA | 11. S. AFRICA |
| 6. AUSTRALIA |               |

However, it should be noted that although these eleven are those modeled by ECON they are not an all inclusive list of countries to be surveyed by a global system. Using the criteria that countries should be included until 99% of the total world production for a crop is accumulated results in the list of countries shown in Figure 2-4. A more refined criteria, although not as inclusive, would be to define a set of critical countries, each of which is a significant contributor to global production. When a critical country is defined as one who contributes at least 5% to the total production of a crop, the set shown in Table 2-1 results. The data used in this table is an average of the 1971-73 production figures published in Agricultural Yearbook, 1974.

Table 2-1. Critical Countries for Global Crop Survey

<u>CRITICAL COUNTRY</u>	<u>CROP (OR CROPS)</u>
UNITED STATES	Wheat, soybeans, corn, barley, oats
USSR	Wheat, barley, oats, rye
CHINA	Wheat, soybeans, rice, corn, barley
CANADA	Wheat, barley, oats
FRANCE	Wheat, barley, oats
INDIA	Wheat, rice
WEST GERMANY	Oats, rye
POLAND	Oats, rye
BRAZIL	Soybeans, corn
UNITED KINGDOM	Barley
INDONESIA	Rice
EAST GERMANY	Rye
THAILAND	Rye
JAPAN	Rice
BANGLADESH	Rice
ARGENTINA (approx. 5%)	Corn, wheat
AUSTRALIA (approx. 5%)	Wheat

The mission requirements that resulted from this phase of TOSS for the Global Crop Survey mission are summarized in Figure 2-5. The system output of current production estimates for each of the seven crops should be publicly disseminated at a regularly established place and time (via the currently established USDA dissemination procedures for example). The frequency of publication should be monthly during the crop seasons with the level of aggregation to the country level. The accuracy goal for the system was established at 95% (on a global basis) with a two sigma confidence level.

<u>WHEAT</u>			<u>SOYBEANS</u>			<u>RYE</u>								
USSR USA CHINA INDIA FRANCE CANADA AUSTRALIA ITALY TURKEY PAKISTAN WEST GERMANY	} 60%	ARGENTINA POLAND ROMANIA UNITED KINGDOM UGOSLAVIA CZECHOSLOVAKIA HUNGARY SPAIN IRAN AFGHANISTAN BULGARIA MEXICO	MOROCCO BRAZIL EGYPT SOUTH AFRICA GREECE SWEDEN ALGERIA BELGIUM EAST GERMANY	USA CHINA BRAZIL INDONESIA USSR MEXICO CANADA ARGENTINA KOREA COLOMBIA	} 95%	PARAGUAY JAPAN THAILAND TAIWAN NIGERIA TURKEY SOUTH AFRICA CAMBODIA IRAN PHILIPPINES	USSR POLAND WEST GERMANY EAST GERMANY USA TURKEY CZECHOSLOVAKIA ARGENTINA AUSTRIA	} 80%	CANADA FRANCE SWEDEN SPAIN HUNGARY DENMARK PORTUGAL YUGOSLAVIA FINLAND NETHERLANDS					
<u>OATS</u>			<u>RICE</u>			<u>BARLEY</u>								
USSR USA CANADA WEST GERMANY POLAND FRANCE SWEDEN AUSTRALIA UNITED KINGDOM FINLAND CHINA		} 80%	CZECHOSLOVAKIA EAST GERMANY ARGENTINA DENMARK SPAIN ITALY TURKEY NORWAY YUGOSLAVIA AUSTRIA BELGIUM ROMANIA IRELAND	CHINA INDIA INDONESIA BANGLADESH JAPAN THAILAND BURMA BRAZIL KOREA SOUTH VIETNAM PHILIPPINES NORTH VIETNAM		} 80%	PAKISTAN TAIWAN EGYPT NEPAL MALAGASY REPUBLIC USSR MALAYSIA IRAN CAMBODIA SRI LANKA (CEYLON) LAOS AFGHANISTAN USA AUSTRALIA		USSR CANADA FRANCE USA UNITED KINGDOM CHINA WEST GERMANY DENMARK SPAIN POLAND CZECHOSLOVAKIA TURKEY EAST GERMANY	} 75%	AUSTRALIA INDIA KOREA SWEDEN ETHIOPIA BULGARIA AUSTRIA MOROCCO IRAN FINLAND HUNGARY GREECE			
<u>CORN</u>														
USA CHINA BRAZIL USSR SOUTH AFRICA FRANCE ROMANIA ARGENTINA MEXICO YUGOSLAVIA			} 70%	INDIA HUNGARY ITALY BULGARIA CANADA INDONESIA EGYPT THAILAND THILIPPINES SPAIN			KENYA NIGERIA RHODESIA MALAWI TURKEY ETHIOPIA AUSTRIA GUATEMALA CZECHOSLOVAKIA							

Figure 2-4. Producing Countries

UPDATE CYCLE MONTHLY; RANGE FROM 2 WEEKS TO 8 WEEKS

TIMELINESS 7 DAYS FROM LAST INPUT, RANGE FROM 4 TO 14 DAYS

SYSTEM ACCURACY GLOBAL PRODUCTION LEVEL 95% ACCURACY, 90% OF THE TIME

OUTPUT PRODUCT TABULATED PRODUCTION ESTIMATES OF MAJOR WORLD CROPS BY COUNTRY

OUTPUT DISTRIBUTION PUBLIC RELEASE AND DISSEMINATION AT FIXED LOCATION AND INTERVALS

AREA OF COVERAGE MAJOR FOOD PRODUCING COUNTRIES (AS REGIONS)

INFORMATION GRID SIZE COUNTRIES, PERHAPS 1 LEVEL SMALLER FOR LARGE COUNTRIES

CRITERIA	CROPS	COUNTRIES
U S ACREAGE	WHEAT	WHEAT = 26 COUNTRIES
U S PRODUCTION	CORN	CORN = 29 COUNTRIES
WORLD ACREAGE		
WORLD PRODUCTION	RICE	RICE = 47 COUNTRIES
U S FARM VALUE	SOYBEANS	SOYBEANS = 19 COUNTRIES
U.S. TRADE	SMALL GRAINS'	
TOTAL WORLD TRADE	- RYE	RYE = 20 COUNTRIES
	- OATS	OATS = 21 COUNTRIES
	- BARLEY	BARLEY = 29 COUNTRIES

Figure 2-5. Data and Mission Requirements - Global Crop Survey

### 2.3 NON CROP SURVEY MISSIONS

The overall objective of TOSS was to establish provable estimates of end-to-end system performance for applications whose economic benefits to the United States was quantifiable. There are dozens of resource management applications which could fruitfully benefit from a remote sensing system, especially one with a Thematic Mapper sensor capability. However, the need to quantify the expected benefits reduced this large number of applications to the four which were economically modeled by ECON Inc. This is not to imply that the other additional missions should not be implemented; but rather, that they were not analysed as part of TOSS.

The two non-crop survey missions modeled by ECON were Rangeland Management and Inland Water Management. They were initially included as part of TOSS but subsequently the study team was redirected to delete them and to concentrate on the crop survey missions. The mission requirements which were obtained for these two applications prior to their deletion from TOSS are presented in Appendix E for the Rangeland mission (summarized in Figure 2-6) and in Appendix F for the Inland Water Management mission (summarized in Figure 2-7).

UPDATE CYCLE, MONTHLY (RANGE FROM WEEKLY TO MONTHLY)

TIMELINESS FORAGE MEASUREMENT - LESS THAN 7 DAYS  
WEATHER - DAILY

SYSTEM ACCURACY > 90% (WITH 2 SIGMA CONFIDENCE LEVEL)

OUTPUT PRODUCT AVAILABLE FORAGE PREDICTION/ESTIMATION

OUTPUT DISTRIBUTION REPORTS TO RANGE MANAGERS BY SUBSCRIPTION

AREA OF COVERAGE RANGELAND OF UNITED STATES  $\approx$  3.8 MILLION SQUARE KILOMETERS

INFORMATION GRID SIZE  $\geq$  2.5 SQUARE KILOMETERS

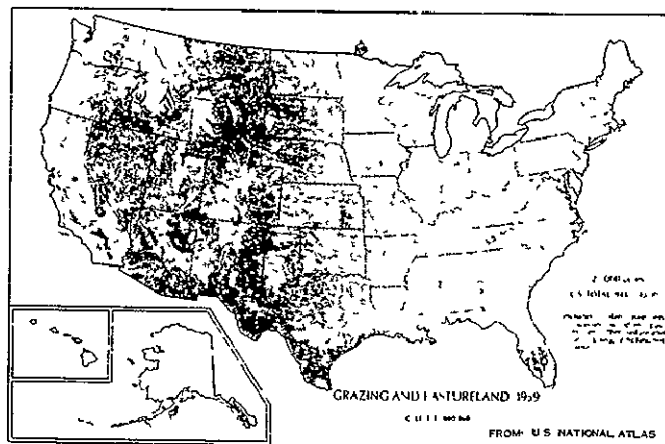


Figure 2-6. Data and Mission Requirements - Rangeland Management

UPDATE CYCLE 4 DAYS, RANGE FROM 2 DAYS TO 2 WEEKS

TIMELINESS 4 DAYS, RANGE FROM 2 DAYS TO 1 WEEK

SYSTEM ACCURACY 90% ACCURACY ON SNOW CONTRIBUTION, RANGE FROM 75% TO 95%

OUTPUT PRODUCT TABULATED AREA MEASUREMENT OF SNOW EXTENT BY SUB BASIN

OUTPUT DISTRIBUTION TO SPECIFIC DAM MANAGERS

AREA OF COVERAGE, TOTAL OF 50 SPECIFIC WATER SHEDS

INFORMATION GRID SIZE WATERSHED SUB BASINS ( $\approx 1 \times 10^3 \text{ km}^2$ )

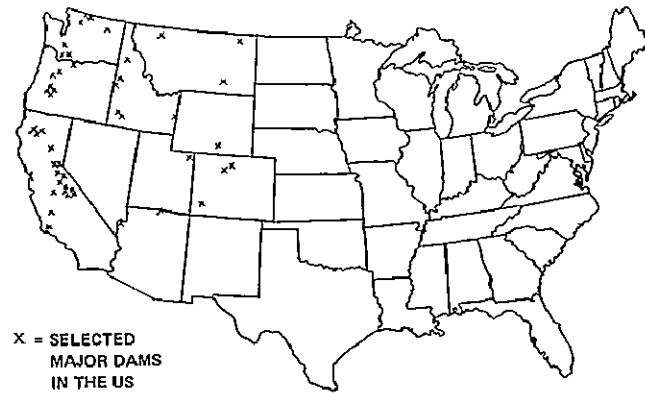


Figure 2-7. Data and Mission Requirements - Inland Water Management

## **SECTION 3**

### **SYSTEM ANALYSIS**



## SECTION 3

### SYSTEM ANALYSIS

One of the singularly unique features of TOSS is the systems analysis performed on the Crop Inventory System in order to translate the mission requirements into a system design. TOSS, through its interdisciplinary approach of engineering together with economics, was able to develop for the first time the relationship between each subsystem characteristics and the overall system performance measured in terms of economic benefit. As remote sensing systems become technically established and begin to be considered for operational applications, it is appropriate that the expected economic benefits to result from that system be used as the metric or measurement criterion for assessing the systems performance. The TOSS analytical structure and tools used to assess the system design and economic performance for a crop inventory application mission also provide the framework within which further refinements of the system design can be evaluated.

In order to accomplish this task, TOSS had to develop the interrelationships between three dissimilar quantities; refer to Figure 3-1. The relationship between the economic benefits and the economic parameters, such as buy/sell decisions, inventory holding pattern decisions, or planting and harvest decisions, has been solved and modeled by ECON Inc. as part of their econometric models. The ECON models were able to develop and maintain a continuous analytical chain from the economic benefits back through to the overall system performance parameters of: accuracy, timeliness, and update cycle. The TOSS effort continued this chain back through to the critical system design parameters such as: IFOV, signal to noise, spectral bands, system timing delays, and number of spacecraft. Throughout the establishment of this analytical chain, several "fly in the ointment" issues arose, such as field size distributions, cloud cover impact, and crop planting densities, which had to be dealt with.

Now, with the TOSS analytical tools and structure, it is possible to quantitatively determine the effect of the various controllable (in an engineering sense) system design parameters on the overall system economic benefits. This section describes in detail the analysis and results which form the unbroken end-to-end analytical linkage.

#### 3.1 OVERALL ANALYSIS STRUCTURE

In a simplified approach, the ECON Inc. economic analysis can be viewed as an econometric model which requires inputs of accuracy, timeliness, and update cycle and which, with these, is able to "create" dollars of economic benefit; refer to Figure 3-2. The input parameter update cycle is the time period between successive public releases of the crop production estimate reports. Throughout the TOSS effort, the update cycle was fixed at 30 days to reflect a monthly reporting rate. The input parameter timeliness is the interval between when the measurements are taken and when the report, based on those measurements is publicly released. The development of the timeliness input parameter is discussed in Section 3.6 below.

## UNDERSTAND AND QUANTITATIVELY RELATE

- THE MISSION
- THE BENEFIT MECHANISMS
- THE SYSTEM PERFORMANCE
- THE SYSTEM DESIGN

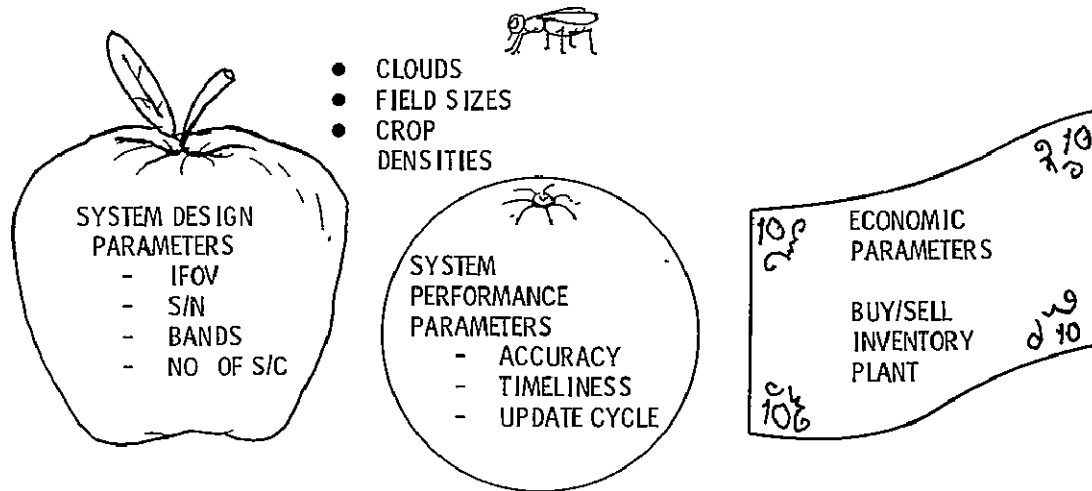


Figure 3-1. TOSS Required Linkage of Dissimilar Elements

The accuracy parameter accounts for all of the errors present in the production estimate at the time of measurement. The source and relationship to the system of the various components which together comprise timeliness and accuracy are shown in Figure 3-3.

The complete system, from the acquisition of scene data through the requisite data handling/processing to the crop production forecast, was partitioned into individual subsystem components that each contribute to overall system accuracy and timeliness. The breakdown permitted determinations of these component parameters from the definable performance characteristics and specifications of an operational system of the 1980's.

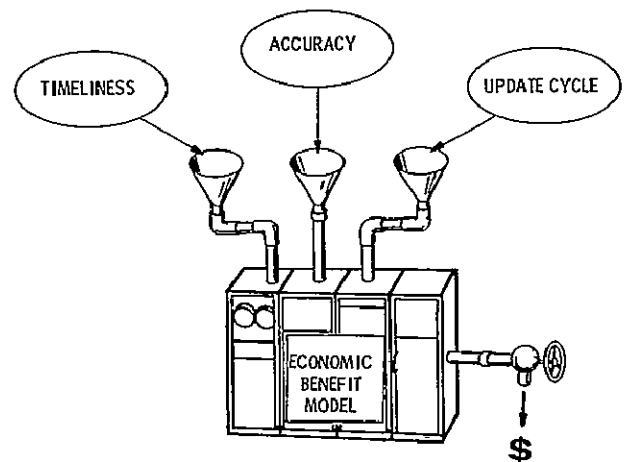
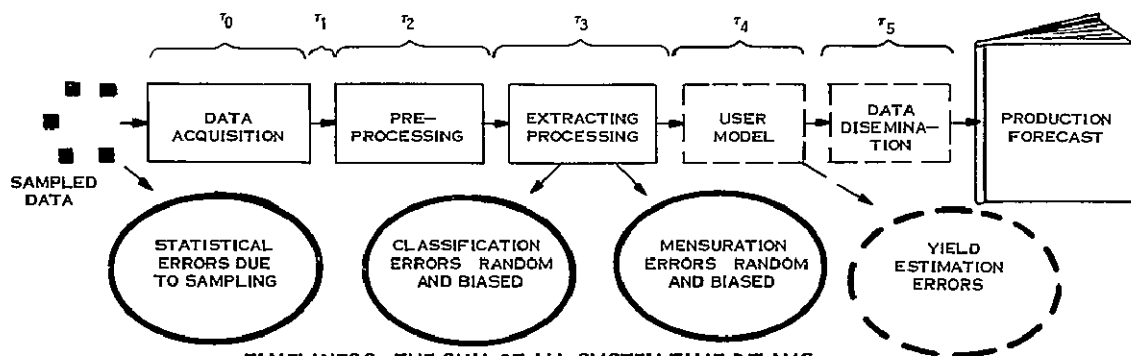


Figure 3-2. Simplified TOSS Engineering - Economic Interface

The following paragraphs will provide a brief overview of these components and their function as context for the analysis.



- TIMELINESS THE SUM OF ALL SYSTEM TIME DELAYS

$$\tau = \sum_{i=0}^5 \tau_i$$

- ACCURACY. EXPECTED VALUE OF ACREAGE MEASUREMENT ERROR IS RSS OF INDEPENDENT ERROR CONTRIBUTIONS

$$\sigma_M = \sqrt{\sum_{i=1}^5 \sigma_i^2}$$

Figure 3-3. Systems Analysis Structure

Data Acquisition. Multispectral scene data is acquired by either a Thematic Mapper (TM) or a Multi-spectral Scanner (MSS) sensor operating in an orbiting spacecraft. The TM baseline specifications were taken to be those defined by the Final Report of the Landsat - D Thematic Mapper Technical Working Group, which met at Purdue University on April 30, May 1 and 2, 1975. The summary from their report appears in Appendix N. The MSS baseline used was that of the four band MSS currently operating on Landsats 1 and 2; the 5 band MSS under consideration for Landsat C was not addressed. For TOSS the key specification differences between the TM and MSS are:

- Spectral Bands: TM-7 bands, which are narrower than MSS; including a thermal infrared band, which was not on MSS.
- Noise: TM requirements greater than MSS.
- Instantaneous Field of View (IFOV): 30 meters for TM, 80 meters for MSS.

The approach taken for the acquisition of scene data for the wheat inventory mission was that of using sampled data (as opposed to a full census). The use of sampled data introduces sampling fluctuations or statistical errors due to sampling, the nature and size of these errors is discussed in Section 3.3 below.

Preprocessing. The primary function of preprocessing is the removal of radiometric and geometric distortions found in raw images. These corrections are examined in Appendix I. The residual errors after preprocessing corrections are applied do not contribute significantly to the overall system error for the type of application under consideration. Preprocessing does, however, affect the system timeliness.

Extractive Processing. The function of the extractive processor is to determine crop acreages from the radiometrically and geometrically corrected sampled scene data. There are two related tasks for this processor; the determination of field areas, mensuration, and, assignment of a particular crop type to those fields, classification. They are related since the ability to perform each depends on how well each field can be distinguished from its neighbors. The type of extractive processor suggested and analyzed by TOSS is a field classifier because of the inherently higher level of information that can be extracted from the available data. The composition of the system error due to the extractive processing function is rather complex and is discussed at length in Section 3.2 following.

User Model. The user model is the functional element in the system flow that takes the estimate of growing acres and by combining it with estimates of yield formulates the desired production estimate. Error is introduced in this function by the error associated with the yield estimate. TOSS did not presume that the remote sensing system would be used to improve the yield forecast process. The yield errors used in TOSS are unbedded in the economic models and are the same as current USDA capabilities. To the extent that yield errors can be reduced, the system performance will further improve, and additional benefits will accrue to the U.S.

Data Dissemination. The data dissemination function provides for taking the total production forecast formed by the user model and distributing it to the using public. The dissemination system for the Crop Inventory System was taken to be the current USDA report distribution process.

The overall system accuracy is analyzed as a combination of errors. The propagation and combination of errors is shown in Figure 3-4, the dashed boxes indicate those errors which are exogenous to the TOSS system per se and are included in the economic models. The acreage estimation error within a measured sample is shown as the combination of four components; this acreage error is discussed in the following section.

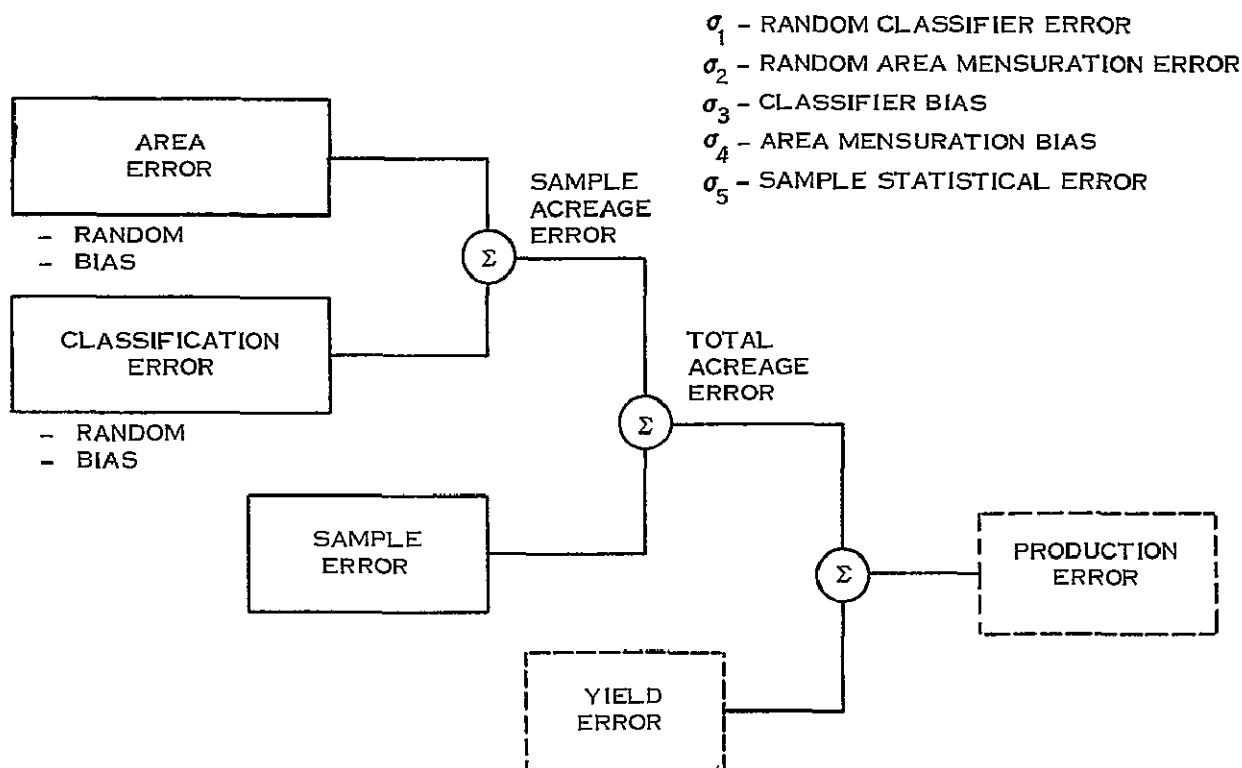


Figure 3-4. System Error Propagation

### 3.2 ACREAGE ESTIMATION PERFORMANCE

The total crop acreage estimation for a country comes from a statistical extrapolation (aggregation) of crop acreage measurements made on a number of randomly selected test areas called sampling units. Extrapolation of these sample unit acreages to a country's total crop acreage includes errors of two types; the measurement error of each sample, and the statistical sampling error of aggregating the samples. Improvements in scanner performance parameters, such as S/N, IFOV, MTF, or number of spectral bands, reduce the acreage error within a sampling unit. The sampling error is reduced by increasing the number of samples collected and/or by improving the sampling plan strategy. The TOSS sampling strategy is that of stratified sampling with optimum sample allocation and is described in Section 3.3, and more completely in Appendix M. This section addresses the acreage error within a measured sample unit.

#### 3.2.1 APPROACH TO SAMPLE CROP ACREAGE ESTIMATION

The TOSS approach to the problem of mensuration and classification of crop fields within a sampling unit uses both the spatial and spectral aspects of the scanner data. This is in contrast to the presently more commonly used pixel by pixel approach, which only uses the spectral information from the scene. The first is a field approach utilizing the fact that by definition every field has only one crop growing in it. The pixel

approach denies this knowledge and allows fields to contain more than one crop, and crops to appear anywhere by classifying every pixel independently of its neighbors.

Pixel approach algorithms are easier to design and implement making them the most commonly used currently. However, very encouraging work on field algorithms has been accomplished in research efforts and indications are that such algorithms could be made ready for the 1980's, the TOSS mission time period.

The performance of a field algorithm using spatial domain information was determined by TOSS by investigating separately the expected area mensuration accuracy and the expected classification accuracy. Each of these was considered as having both "bias" and random error components. Random errors are those which are independent from one field to the next and thus are averaged down by the number of fields measured. "Bias" errors are not truly biases or modeling errors but rather are slowly varying errors which are not independent from one measurement to the next.

### 3.2.2 MENSURATION ACCURACY ANALYSIS

The wheat crop inventory mission requires an inventory of growing wheat acreage in the U.S. and eleven specific (for the ECON model) foreign countries. Wheat, and most other crops as well, grows in contiguous areas known as fields. The ground scenes of interest consist then of variously shaped, different sized fields each of which has a spatially uniform (relatively) radiance. One of the tasks of the extractive processor is to locate spatially the boundary of each field thru the implementation of an algorithm that operates on scene data. The field algorithm analyzed by TOSS first locates regions of homogeneous radiance and then the boundaries between these regions. The assumption was made that the boundary of each field is formed by lines (borders) across which there is a discontinuous radiance change. This definition of a field is that of remote sensing and is different from the more commonly used definition of a field; the remote sensing field is that which looks like a field irrespective of ownership boundaries. For example, two adjoining plots of wheat, owned by different farmers, separated only by a barbed wire fence would look to the remote sensing system as a single large field; they would not be counted as two fields.

The response of the scanner, either TM or MSS, to a discontinuous radiance change will depend primarily on its instantaneous field of view (IFOV) and modulation transfer function (MTF). The IFOV is a measure of the ground area that the scanner would "see" if its system frequency response, indicated by its MTF, were an ideal - constant amplitude and unlimited bandwidth. Nominally the IFOV is a square, 80 meter on a side for MSS and 30 meters for TM. The non-ideal actual MTF for each scanner, however, results in its signal at any instant being its response to not only the radiance in the IFOV but to recently inputted radiances. The IFOV can be altered from its nominal square shape to include the effect of MTF. This is done by enlarging it and introducing a window with spatially varying transmissivity. Further modifications

to this "effective IFOV" can account for distortions due to the optics and the spatially non uniform detector response of the actual scanner. It was assumed for the TOSS analysis that the effective IFOV is equal to the nominal IFOV for the TM and MSS.

A very important scanner performance parameter is its signal to noise ratio, S/N. The predominate scanner noise sources are the detectors. Additional noise is introduced by atmospheric nonuniformities and scene reflectance irregularities. TOSS assumed that the last two contributions were negligible. This amounts to a further specification of the scene model, requiring the radiance from each field not to be a function of positions within the field.

A key factor in assessing a scanner's ability to determine a field area is the field's size and shape. It was assumed that only fields large compared to the IFOV can be mensurated, and for the numerical calculations square fields were used with an edge parallel to scan direction. Fields with other orientations were analyzed and it was found that they can be measured with only slightly reduced accuracy. The radiance contrast from one field to the next,  $\Delta R$ , used for the calculations was assumed to be at least 10% of full scale in one spectral band.

A cutoff of 16 IFOV's was assumed for both TM and MSS. Cutoff means that (square) fields with areas less than that corresponding to 16 IFOV's will not be mensurated, while larger fields will be. The introduction of a cutoff area unique for each scanner (10.24 HA for MSS and 1.44 HA for TM) divides all the fields of a country into a set of fields that can be mensurated from scanner data and a set that can not.

#### 3.2.2.1 Random Mensuration Error (Fields above cutoff size)

TOSS examined the accumulated error for areas of measured fields (those exceeding cutoff size). Using the assumptions that have been cited above and others of less significance, which are covered in Appendix G, the following was demonstrated.

##### (a) Relative error in individual rectangular fields

$$\frac{\sigma}{A} = 2\sqrt{2} \left(1 + \frac{1}{\alpha^2}\right)^{1/2} \rho \frac{w}{L}$$

where  $\alpha = \frac{\text{rectangle width}}{\text{rectangle length}} = \text{aspect ratio}$

$\rho$  = noise equivalent radiance divided by field to field radiance difference  $\Delta R$

$w$  = IFOV

$L$  = rectangle length (length of field size)

For square fields and  $\Delta R = 10\%$  of full scale, Figure 3-5 gives the area error in percentage employing MSS band 1 and TM band 2.

It probably should be emphasized that a number of assumptions have been made to obtain the curves in this figure and any use of them outside their TOSS context should be discriminating. For the TOSS analysis they provided representative optimal numerical values for the area mensuration accuracy for individual fields above cutoff size, using an MSS and a TM based scanner system.

(b) Relative error in total acreage

$$\frac{\sigma_{A_T}}{A_T} = \left\{ \frac{8 w^2 \sum (1 + \alpha_i^2) L_i^2 \rho_i^2}{\left[ \sum \alpha_i L_i^2 \right]^2} \right\}^{1/2}$$

where each field making up to total area  $A_T$  is rectangular. Subscripted quantities represent individual field values.

The importance of this last result is that it leads to the conclusion that the total acreage relative

error decreases as one over the square root of the total acreage. The basic reason for this conclusion is that the area mensuration errors for individual fields are random and tend to cancel when aggregated.

### 3.2.2.2 Mensuration Bias Error Component

For purposes of the TOSS analysis it was assumed that the remote sensing system would have no capability to measure wheat acreage contained in fields of a size smaller than sixteen IFOV's in area. Refer to Section 3.7 for a complete discussion of the TOSS field size analysis results. This assumption is necessitated in part by the difficulty of devising accurate analytical models for very small fields, and more importantly, by the inability of spatial domain classifiers (i.e. per field classifiers) to operate successfully on small fields. The wheat acreage contained in small fields, those of a size smaller than the sixteen IFOV cutoff, will need to be estimated or accounted for separately from the remotely sensed wheat acreage measurement.

The simple approach used in TOSS to account for these small fields is to estimate their wheat area based on the measured wheat area in the larger fields. If small fields correlate well with large fields then the total wheat area can be estimated by applying a factor to the measured large field area. To the extent that small fields do not correlate with large fields, an error will be introduced by this procedure in the total acreage estimate. This error will be fixed from year to year (since past data will be used to establish the correction factor) and cannot be "averaged down" by measuring more fields. This error is therefore referred as the small field cutoff bias error, or the mensuration bias error,  $\sigma_4$ .

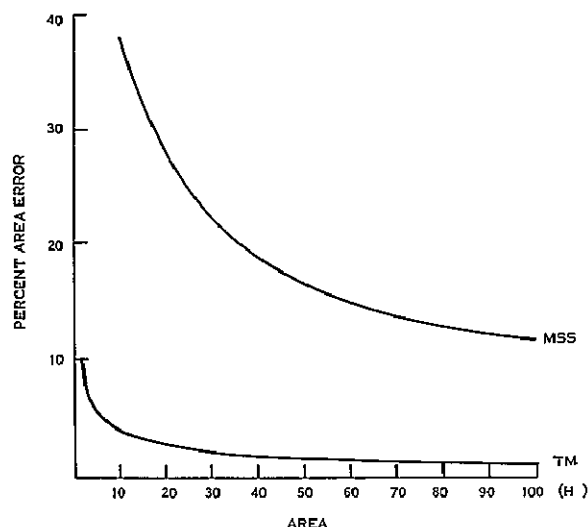


Figure 3-5. Square Field Area Error



In order to establish the size of this mensuration bias error component the correlation of large fields to small fields was investigated. The variation over time of this correlation will apply to the area unseen by the sensor (area below the cutoff on field size distribution curves) to create the mensuration bias error component for TOSS. If a correction factor,  $f$ , is defined as the ratio of the area below the cutoff to the area above the cutoff then the total wheat acreage will be estimated by

$$A_{\text{total}} = (1 + f) A_{\text{Measured}}$$

and the error will be given by

$$\sigma_{\pm} = \frac{f}{(1 + f)} \sigma_f$$

where  $\sigma_f$  is the coefficient of variation (standard deviation divided by mean) of  $f$  (large field to small field correlation).

The variation in the large field to small field correlation, as measured by  $\sigma_f$ , was approximated by computing the variation in the correlation of areas with large farms to areas with small farms. In the United States, four groups of states were defined, two with relatively large farms and two with relatively small farms.\* The groups and their average farm sizes are:

L1	North Dakota	972 acres	L2	Oregon	967 acres
	Kansas	692		Nebraska	705
	Oklahoma	616		South Dakota	978
	Texas	1078		Colorado	1583
	Washington	669		Idaho	650
	California	630			
S1	Pennsylvania	177 acres	S2	New Jersey	155 acres
	Minnesota	297		Maryland	207
	North Carolina	145		Michigan	207
	Arkansas	381		Ohio	209
				Missouri	313
				South Carolina	299

For each combination of large and small groups, the ratio of acres harvested\*\* (large/small) was computed by year over the period 1969 to 1974 and the mean and standard deviations of the ratios taken. These computations are summarized in Table 3-1. The average variation for the US is 16.7%.

\*Farmland Tenure Patterns in the US, USDA Agricultural Economic Report No. 249, February 1974.

\*\*The '69 to '71 statistics are from Agricultural Statistics 1972 and the '72 to '74 data is from Crop Production - 1974 Annual Summary, both are USDA publications.

Table 3-1. Computation of  $\sigma_f$  for United States

Ratio	Crop Year						Mean	Standard Deviation	$\sigma_f$
	'69	'70	'71	'72	'73	'74			
L1/S1	10.65	9.82	7.30	7.63	7.77	6.12	$\bar{x} = 8.22$	1.54	18.73%
L2/S2	3.54	3.71	4.11	3.65	4.78	3.29	$\bar{x} = 3.85$	.48	12.47%
L1/S2	8.93	9.03	9.73	9.34	13.00	8.48	$\bar{x} = 9.75$	1.50	15.38%
L2/S1	4.23	4.03	3.08	2.98	2.85	2.37	$\bar{x} = 3.26$	.66	20.25%

average  $\sigma_f$  is 16.7%

Similar computations were done for foreign countries by using Australia to represent large fields and India to represent small. The percentage variation in the correlation was thus established for the foreign countries to be 25.97%.

When these correlation variations,  $\sigma_f$ , are combined with the correction factor,  $f$ , for each country the mensuration bias error term,  $\sigma_4$ , is thus obtained. These computations are shown in Table 3-2 for each of the eleven economically modeled countries.

Table 3-2. Mensuration Bias (small field bias),  $\sigma_4$ 

	f		$\sigma_f$	$\sigma_4 = \frac{\sigma_f}{(1+f)} f$	
	MSS	TM		MSS	TM
USA	.25	.2	.1670	.0334	.0278
USSR	.01	N.A.	.2597	.0026	-0-
UK	11.5	.45	.2597	.2389	.0806
CANADA	.27	.024	.2597	.0552	.0061
ARGENTINA	.05	.006	.2597	.0124	.0015
AUSTRALIA	.005	N.A.	.2597	.0013	-0-
SPAIN	.25	.2	.2597	.0334	.0278
FRANCE	11.5	.45	.2597	.2389	.0806
ITALY	11.5	.45	.2597	.2389	.0806
INDIA	.52	.05	.2597	.0888	.0124
S. AFRICA	.25	.02	.2597	.0334	.0051

\*The '69 to '71 statistics are from Agricultural Statistics 1972 and the '72 to '74 data is from Crop Production - 1974 Annual Summary, both are USDA publications.

### 3.2.3 CLASSIFICATION ACCURACY ANALYSIS

The determination of the classification accuracy can be done independently of the mensuration accuracy analysis because after the initial location of a spatially uniform radiance region (field) the mensuration of the field is derived from the border, or mixed pixels while the classification of that fields contents derived from the interior, or pure, pixels.

The goals of the TOSS classification analysis were (1) the formulation of a classification technique that could or would be operational by the 1980's and be superior to other techniques and (2) the determination of the sensitivity of this technique to key system parameters in particular those that are different in MSS and TM scanner based systems. With the baseline of a per field classifier, TOSS proceeded to the problem of determining its sensitivity to key system parameters. A MonteCarlo simulation of a Bayesian (optimal) per field classifier was used to quantify the accuracy dependence on system parameters (e.g. S/N, IFOV) that vary between an MSS and a TM based system.

The overall functional flow of the classifier performance simulation is shown in Figure 3-6. The simulation accepts as input definitions of (1) signature characteristics, (2) sensor characteristics, and (3) classifier characteristics and produces estimates of classifier accuracy as its output. The overall flow begins by taking the basic crop signature statistics and degrading them (by increasing the variance) for the intra-field variation and the sensor noise characteristics in order to represent the data actually "seen" at the classifier. For a per field classifier extractive processing technique, the sensor IFOV and the field size determine the number of observations which will be taken of the field's radiance. This number of pixels is used to reduce the variance of the field signature by "averaging down" the intra-field variations and the sensor noise. The result, at this point in the simulation flow, is a set of means and variances for each band for each crop type. In other words, the spectral space distribution of the field clusters. The simulation then randomly selects a set of radiance values for a field from the distribution and classifies it in accordance with a Bayesian classifier. For each crop type the simulation iterates this step 1,000 times to gather classification performance data, omission and commission error rates.

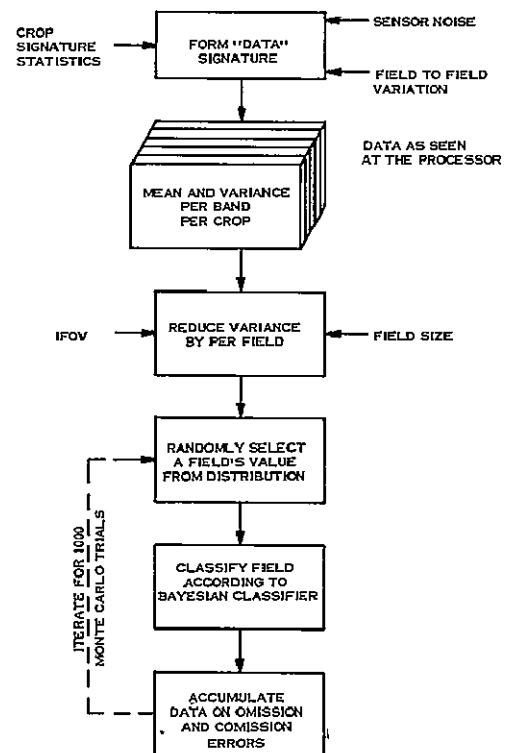


Figure 3-6. TOSS Classifier Performance Simulator

The simulation supposed that there were ten different crops, and the fields were square. Multispectral data from an MSS based system were used in a per field classifier, and the results compared for accuracy with those obtained with multispectral data from a TM based system. Each crop's data were assumed to have a multivariate normal distribution. Means and standard deviations for the distribution were entered into the model.

A problem overcome in the TOSS study was the lack of representative values for crop means and covariance values. The mean and standard deviation values shown in Tables 3-4 and 3-5 were selected from CITARS\* data which were taken to be representative of MSS data directly. For the TM, the first four bands were taken to be the same as the MSS; the additional 3 bands were approximated by selecting additional spectral values from Table 3-4. Although the justification for the selection of this data could be stronger, TOSS had to use the best data which time and availability permitted. Covariance (off diagonal) values were not used because of their complete unavailability.

Table 3-4. MSS and TM Band Means for Simulation Model

Simulated Class	TM						
	MSS				5	6	7
	1	2	3	4			
1	32.43	25.36	48.46	27.25	25.3	53.4	39.8
2	37.1	33.00	45.81	23.86	28.67	65.00	60.11
3	30.64	19.93	56.69	34.64	31.74	62.63	41.95
4	63.27	74.55	79.64	35.00	32.88	74.12	69.88
5	32.95	24.64	54.45	30.64	21.11	52.67	49.67
6	49.83	51.70	65.48	30.83	32.53	53.43	18.61
7	27.69	18.14	48.12	29.77	32.35	71.30	60.70
8	54.43	60.70	71.30	32.55	29.77	48.12	18.14
9	28.52	18.61	53.43	32.53	30.83	65.48	51.70
10	49.78	49.67	52.67	21.11	30.64	54.45	24.64

\*CITARS Report Vol. VIII, Part 6 JSC 09391, Table V - Page 11.

Table 3-5. MSS and TM Standard Deviations for Simulation Model

Simulated Class	TM						
	MSS				5	6	7
	1	2	3	4			
1	1.64	1.86	2.04	1.48	1.64	1.86	2.04
2	2.11	3.61	2.06	1.46	2.11	3.61	2.06
3	1.72	1.73	2.25	1.46	1.72	1.73	2.25
4	1.29	0.50	2.35	1.76	1.29	0.50	2.35
5	1.33	2.50	2.29	1.94	1.33	2.50	2.29
6	2.06	2.46	2.73	1.31	2.06	2.46	2.73
7	1.00	1.60	1.97	1.48	1.00	1.60	1.97
8	2.10	3.08	1.57	1.43	2.10	3.08	1.57
9	1.11	1.48	2.64	1.47	1.11	1.48	2.64
10	2.66	3.68	4.47	2.92	2.66	3.68	4.47

It clearly would be profitable to TOSS if actual values or as nearly actual as possible were used in the simulation model. With more time and resources, better values could be obtained from multispectral data from other scanners (e.g., NASA 24 Band). Another approach would be the extrapolation and/or interpolation of the poorer spectral resolution (4 band) MSS data through independently measured spectro-radiometric curves to estimate (7 band) TM data.

The variances corresponding to the above standard deviations were considered to be a measure of the variation of each crop within a particular field, a local variation. Two additional variances were added for each band of each crop: one accounted for the scanner noise,  $NE \Delta\rho$ , and the other for what might be called inter-field or global variation. The latter tried to adjust for spectral variations from field to field for the same crop. The value assumed for this was 7% (standard deviation, % of full scale in each band).

The simulated classifier used interior pixels only, border pixels and next to border pixels were eliminated. If  $L$  is the side of a (square) in units of IFOV, the number of IFOV used for classification is the square of  $L$  minus 3 after discarding any fractional IFOV's. For example if  $L = 4.2$  IFOV, there is only one usable IFOV.

TOSS assumed that at least one IFOV was required for classification. Therefore, fields with areas less than 16 IFOV can not be classified, and as seen in Section 3.2.2.1 they also can not be mensurated. These smaller fields are treated in Section 3.2.2.2 as a "small field bias error".

Classification of a particular sized field was based on the band by band average over data from the interior pixels. Let us suppose that a field size greater than the cutoff has been selected giving rise to N pixels for classifications. Each pixel supplies four values corresponding to the MSS's four bands (or seven values for the TM). Averaging each band over the N pixels produces four (or seven) band means. Their statistical properties are:

- Expectation values are those given in Table 3-4 for each of the ten crops.
- Variances are given by:

$$\frac{\sigma_1^2}{N} + \sigma_c^2 + \frac{\sigma_n^2}{N}$$

where  $\sigma_i$  with  $i = 1$  thru 4 (or 1 thru 7) are the standard deviations of Table 3-5 for each of the ten crops,  $\sigma_c^2$  is the previously discussed field to field variance, and  $\sigma_n^2$  is the scanner noise variance.

Averaging over the N pixels results then in a reduction for two of the variance components, thereby producing statistical distributions that are narrower and more easily separated spectrally than those corresponding to single pixels. This is seen to be another way of saying per field classifiers are better than per pixel classifiers.

Equal a priori probabilities were assumed for the ten crops. A departure from this assumption would not have a marked affect on the results.

The classifier decision rule was Bayesian. A field was classified to be a certain crop if the probability of a given band by band average taken from the field was greater for that crop than each of the other nine crops. The probability distribution for each crop was multivariate normal with the expectation values and variances for fields; values for fields with N interior pixels are given above.

The probability that a field with N interior pixels and a given crop is classified correctly was determined from the Monte Carlo simulation of the classifier. One thousand band by band averages were randomly chosen from each crop's probability distribution and classified. The ratio of number of correct classifications to number of trials equaled the desired probability of correct classification.

The simulation was used to compare the per field classifier performance using MSS and TM derived data as a function of field sizes, see Figure 3-7. Appendix H contains this and other results of the simulation. Results for sensitivity to the number of bits per sample and classifier training error rate are also given. The training error attempted to deal with the circumstance that the training fields are mislabeled.

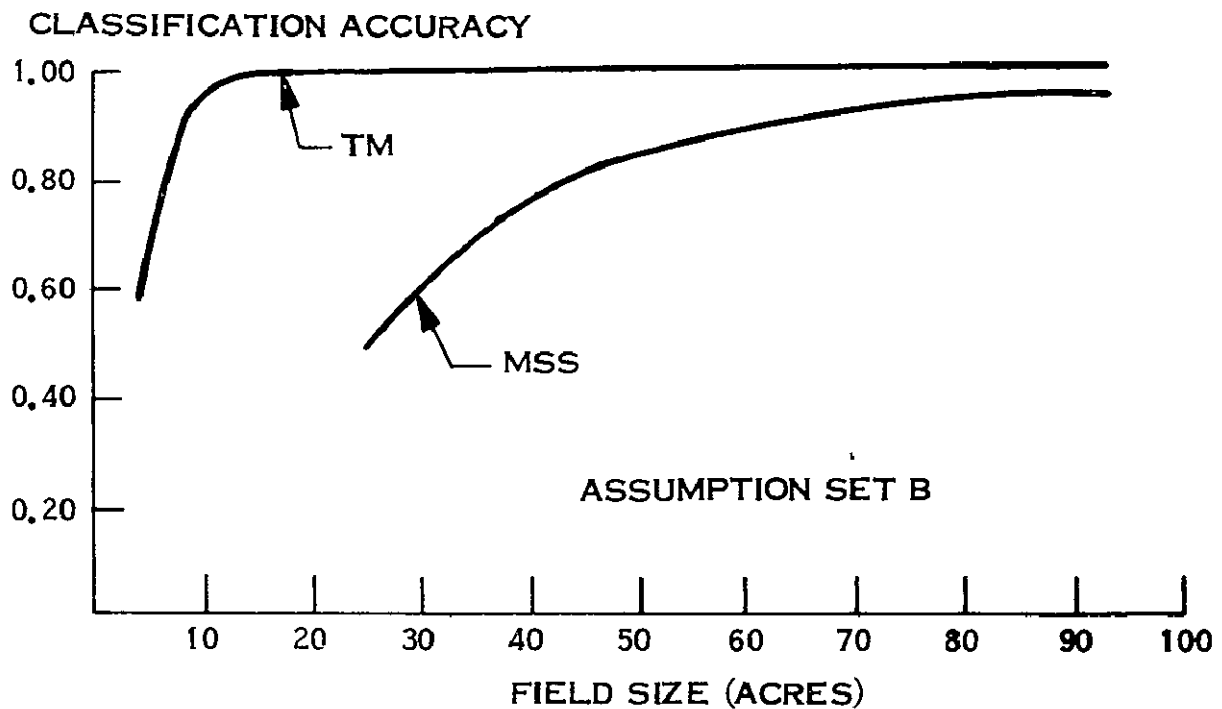


Figure 3-7. Sensor Comparisons for Classification

### 3.2.3.1 Random Classification Error

The classification probabilities calculated from the Monte Carlo simulation permit the calculation of the per field classifier accuracy when applied to a number of fields.

Assume there are  $N_1$  fields with a particular crop C and  $N_2$  fields of another crop  $\bar{C}$  for a total of  $N_T$  fields. Let  $P_C$  and  $P_{\bar{C}}$  equal the probability that each of  $N_1$  and  $N_2$  fields respectively are classified as crop C.  $P_C$  and  $P_{\bar{C}}$  can be calculated from the simulation described above. The number of fields  $N_C$  classified as crop C out of the total  $N_T$  is a random variable whose variance

$$\text{Var}[N_C] = N_1 P_C (1 - P_C) + N_2 P_{\bar{C}} (1 - P_{\bar{C}})$$

This is because  $N_C$  is the sum of two binominally distributed independent random variables; one is the number of  $N_1$  fields correctly classified as Crop C and the other is the number of  $N_2$  fields incorrectly classified as Crop C.

The random classification relative error  $\sigma_1$  satisfies

$$\sigma_1^2 = \frac{\text{Var}[N_C]}{N_1}$$

$$\sigma_1^2 = \frac{P P_c (1 - P_c) + (1 - P) P_{\bar{c}} (1 - P_{\bar{c}})}{N_T P^2}$$

where the a priori probability of Crop C is

$$p = \frac{N_1}{N_T} \text{ and crop c is } 1 - p = \frac{N_2}{N_T}$$

The reciprocal dependence of  $\sigma_1^2$  on  $N_T$  leads to the fortunate decrease in the random classification relative error  $\sigma_1$  as the total number of fields are increased. The basis for this is the tendency of random errors to cancel when aggregated.

### 3.2.3.2 Classifier Bias Error

In the preceding section we considered the variance of  $N_c$ , the number of fields classified as the crop C out of a total  $N_T$  fields with both a crop C and a crop  $\bar{C}$ . We will consider in this section the expectation value of  $N_c$ , which unfortunately is not necessarily equal to  $N_1$ . That is,

$$\begin{aligned} E N_c &= N_1 P_c + N_2 P_{\bar{c}} \\ &= N_1 - N_1 (1 - P_c) + N_2 P_{\bar{c}} \end{aligned}$$

$$E N_c = N_1 \text{ if and only if}$$

$$N_1 (1 - P_c) = N_2 P_{\bar{c}}$$

This last relation is the condition that the number of incorrectly classified fields with crop c equals the number of incorrectly classified fields of crop  $\bar{c}$ ; in other words the omission error equals the commission error. The (simulated) Bayesian classifier, which is used to calculate  $P_c$  and  $P_{\bar{c}}$  is based on a minimization of the sum of these two complementary errors and not on their equality. Therefore, it is to be expected that the omission and commission errors will be different and that the expectation value of  $N_c$  will not be equal to  $N_1$ . The classifier is therefore biased, and it must be corrected.

The knowledge of the a priori probabilities  $p$  and their percent variances  $\sigma_p^2$  permit the introduction of a bias correction factor for  $N_c$ . This factor, developed in Appendix P,

$$\text{equals } \frac{P}{P P_c + (1 - P) P_{\bar{c}}}$$

$$\text{with a relative variance of } \frac{P_{\bar{c}}^2}{P} \sigma_p^2$$



This variance represents the classifier bias error. In contrast to the random classification error the bias error is not a function of the total number of fields  $N_T$ , and unfortunately does not decrease as  $1/N_T$  as does the random error.

### 3.3 STATISTICAL SAMPLING ACCURACY

In the application of remote sensing to an inventory type application mission a fundamental choice exists. The system can gather data over the entire area of interest or the system can sample representative locations within the area of interest and make an estimate of the desired total based on these samples. For the two missions at hand, US and Global Crop Survey, the area of interest is finite but very large; the volume of data that would need to be processed for a complete survey would be tremendous. The use of a carefully designed sampling plan will enable the compilation of adequately accurate answers while processing only a fraction of the total data. Even if a system attempted to enumerate or census all of the relevant crop land, the presence of clouds would most certainly obscure some of the desired data and require that an extrapolation be made in order to estimate the desired totals. Thus, the crop inventory mission approach is basically a sampled data approach; the remaining question is how to do it most efficiently.

The use of any sampled data approach introduces a sampling error (sometimes referred to as sampling fluctuation) in the total estimate due to the variations and unrepresentativeness of the samples selected. The size of this sampling error can be estimated, at different confidence levels, by knowing some characteristics about the population which is being sampled and the type of sampling plan used. In fact, the goal in designing that sampling plan is to optimize the tradeoff between the error introduced by sampling and the cost of the sampling plan used.

The cost of acquiring sample data with a satellite based remote sensing system is relatively fixed over a broad range of number of samples obtained. The major cost variable is the cost associated with processing each sample and obtaining the necessary ancillary data required for that processing. Because of the large economic benefits associated with high accuracy for the crop inventory missions, it is desirable to reduce the sampling error contribution as much as possible (within reasonable constraints).

A very detailed discussion of the TOSS statistical sampling analysis is contained in Appendix M of this report. This section summarizes and highlights the key results of that activity as it relates to the overall system analysis. The reader interested in more detail or in the derivation of the underlying mathematics is referred to the Appendix.

### 3.3.1 WHEAT SURVEY SAMPLE DESIGN

The basic sampling approach used for TOSS is that of a stratified population with samples optimally allocated among the strata. When designing such a sampling plan, it is required that certain characteristic data about the population to be sampled be used to design the plan. When no prior knowledge about the population exists, then the optimal plan is to randomly distribute the available samples through the population. As information becomes available with respect to the density and variance of the characteristic to be estimated (as a function of location area), it is possible to design a stratified sampling plan which is more efficient than a simple random sampling. "Efficiency" means more accurate for a given number of samples for the same confidence level.

For the purpose of the TOSS analysis a stratified sampling plan was developed which optimally allocated samples to strata based on wheat planting density, and acres of wheat planted. For the analysis, the world was only stratified to the country level except for USA and USSR. The USSR was further stratified to the economic region level and the USA further stratified to the state level. These levels of stratification were primarily selected because of the difficulty in obtaining the data necessary to permit further stratification within the resources of the TOSS effort. If further stratification were performed and analyzed the resulting sampling errors would be lower than those used in the TOSS analysis. That is, the TOSS analysis is conservative in its estimation of system performance by understating the achievable sampling accuracy.

The degree of stratification envisioned for the actual sampling plan to be implemented as part of the operational system is greater than that used in the analysis. The United States should be stratified to a sub-state level using counties and county level data as the building blocks. Foreign countries should similarly be further stratified to the extent that data can be obtained. It is worth noting that agricultural sampling plans are dynamic over time. Due to the changes in farming practices and land utilization, no plan designed today with the available data will be optimal for implementation in 1980. The specific plan to be implemented must be recomputed based on the latest data just prior to the operational utilization of the system. In fact, during the system's life the plan should be periodically updated and adjusted to account for changes in the basic agricultural patterns of the world.

In order to provide an upper bound on the number of samples to consider for TOSS, it was decided that 50,000 samples would represent the limit that could be processed per month through the extractive processing subsystem. Of these 50,000 samples (each 4 x 4 miles) it was decided to allocate 30,000 to the eleven specific countries treated in the ECON econometric model and to distribute the remaining 20,000 samples to the other wheat producing countries of the world. Note that the eleven economically modeled countries account for over two-thirds of the world's wheat production. The statistical sampling error (sampling fluctuation error) used in the TOSS analysis as a function of the number of samples is shown in Table 3-6.

Table 3-6. TOSS Sampling Errors

	Samples for 10 Countries			
	4,000	12,000	18,000	25,000
USSR	3.82	2.21	1.80	1.50
UK	33.28	19.21	15.69	13.30
Canada	10.03	5.79	4.73	4.0
Argentina	16.72	9.66	7.88	6.7
Australia	10.76	6.21	5.07	4.3
Spain	20.60	11.89	9.71	8.2
France	17.26	9.97	8.14	6.9
Italy	16.76	9.67	7.90	6.7
India	8.72	5.04	4.11	3.5
South Africa	24.59	14.40	11.76	10.0

	Samples for USA		
	1,000	5,000	10,000
USA	6.66	2.98	2.11

values are expressed as percentage errors  
(3.82 is 3.82%)

When reviewing the sampling errors presented in Table 3-6 it should be recalled that these are conservative (understatements) estimates of sampling accuracies. The computations were based on a relatively rudimentary degree of stratification and had an extremely conservative estimate of the effect of clustering. As will be pointed out in Section 3.3.3 below, these estimates are probably too conservative. It is not at all inconceivable that much better sampling accuracies could be obtained from far fewer samples.

### 3.3.2 MULTIPLE CROP SAMPLING PLAN

The development of an efficient sampling plan which can be used to inventory several crops at once is more complex than that for a single crop such as wheat. The approach developed for multiple crop sampling in TOSS consists of combining several single crop sampling plans (one for each crop) into a single unified plan. The resulting plan will produce at least the required sampling accuracy for several designated crops and the accuracy for other crops (not designated as major) can be determined.

The procedure for formulating the multiple crop sampling plan begins by stratifying the reportable area (country or state) into strata for each crop independently. Each subunit of the area, counties in the case of a state area, is identified as belonging to a particular stratum for each crop. For example in Kansas, Rush County might be assigned to stratum number 1 for wheat, stratum number 3 for corn, and stratum number 2 for rice, etc. Then, a required state level sampling accuracy is established for each major crop

(say wheat and corn but not rice) based on a Neyman allocation from the required national accuracy. When the number of samples thus determined for each crop individually is allocated down to the county level then the largest number of samples for that county (from any of the major crops) will be used for that county in the final plan. For example, if Rush County were to receive three samples for wheat in a wheat only plan and five samples for corn in a corn only plan, then Rush County would be assigned five samples (larger of the two major crops) in the final plan. This procedure will ensure that at least enough samples are allocated for each of the major crops within the state. The minor (for the state) crops are not allowed to so drive the sample design; they receive the plan they get from the major crops. Their sampling accuracy can, however, still be computed.

### 3.3.3 INDEPENDENCE OF SAMPLES

The sample unit used in TOSS is a square area of 4 x 4 miles which is measured and used to aggregate statistics for a much larger area. Each sample unit is randomly selected from within a stratum and thus represents an independent observation of the data or characteristic being measured (acres of wheat). The computations of sampling accuracy are highly dependent on the number of independent observations being made in the survey.

Actually there are many observations being made even within a sample; each pixel is really an observation of the ground scene. The key issue however is how independent is each pixel's observation. If each pixel were able to be considered as an independent observation of the wheat acreage then the "effective" number of independent samples would be much larger and the corresponding sampling error would be much lower. But each pixel is not independent however, because they are constrained to be contiguous within a 4 x 4 mile sample unit. Because wheat is grown in fields (where fields are larger than pixels) there is a high degree of correlation among pixels; if one pixel is wheat then the adjoining pixel is quite likely to also be wheat. Thus, the number of pixels in a sample unit cannot be used to reflect the effective number of independent observations.

Similarly, the next step up is to consider the number of fields within a sample unit; there are generally several score fields in a sample unit. However, even at this level a correlation among the fields exists. For example, if a given field contains wheat then the adjoining fields are more likely than not to also contain wheat (because this is a good area for wheat, or the price of wheat looked good this year, or there was a big sale on seed wheat in the fall, etc.). Several attempts have been made in the past to quantify this field-to-field clustering but no general analysis exists. Thus, the number of fields in a sample unit cannot be used to establish the effective number of independent observations either.

The true number of independent observations contained in a sample probably lies somewhere between one (the sample unit itself) and the number of fields per sample. In order to avoid certain controversy and to assure conservatism, the TOSS study used the value one in all of the analyses. In retrospect, this was perhaps too conservative and may have significantly understated the true system performance.

### 3.3.4 DETERMINATION OF SAMPLE UNIT SIZE

This section will address the determination of the sample unit size (e.g., 5 x 6 miles) to be used for the TOSS agriculture missions. There are several interrelated considerations which bear on the question of determining the optimal size; each will be addressed separately.

#### Statistical Accuracy

In general it is desirable to have a large number of independent samples in order to reduce the variance (increase the confidence) of the statistically obtained estimate. For any given volume of data to be processed (x bits of data or y acres of cropland), this consideration would prefer a large number of (small) independent samples rather than a few (larger) samples of equivalent total data volume. Note that clustering of samples (multiple samples within a selected sample unit) may tend to diminish the impact of larger sample units; clustering was the subject of the previous section.

#### Signature Extension

The current ability to apply multispectral analysis techniques over large geographic distances is limited by changes in the atmosphere over these distances which adversely affect classification accuracy. The specific effects of the atmosphere (and other factors such as soil type) on signature extension are not well quantified; however, in general this consideration indicates that smaller sample units are desirable.

#### Training Time

A major cost of multispectral analysis is the cost and time of locating and training the classification signature with "known" training sites. Once this signature is determined, it can be applied rather efficiently over the entire sample unit. This consideration indicates that the sample unit size should be larger in order that fewer training sites be required.

#### Processing Quantums

The implementation of the hardware system will occur in quantum levels of capability rather than in a fully continuous range. For example, the amount of immediately available random access storage is normally found to be 16K, 32K, 64K, 128K, etc; a requirement for 70K of storage would not be a "natural" fit with the available quantum levels. With respect to our concept of the implementation system, the quantum of concern is the amount of data that can be completely displayed on a CRT screen with adequate fidelity. Considering a standard CRT and the pixel size to be about 30 meters, the equivalent quantum step for sample unit size is 4 x 4 miles (for a square sample with 25% side margins to assist in establishing context).

### Field Size

Except for improvements in classification accuracy there is little to be gained from sample unit sizes in the range from a single pixel (smallest size possible anyway) to a size equal to the size of a field. Since all pixels within the same field are highly correlated (if one pixel is wheat the others are likely to be wheat too) little (or no) additional information, in the sampling sense, is provided. This consideration equates all sample unit sizes in the pixel to field size range and effectively sets a minimum sample unit size of from 20 to 100 acres.

### Sampling Cost

The overall objective is to achieve the required sampling accuracy at the minimum cost with due attention given to each of the considerations of this section. Although it is beyond the limits of this study to formulate a complete cost expression, there is one dominant cost relationship which can be considered. The training and overhead (image selection, preprocessing, registration, ground truth, etc.) cost associated with each sample will be relatively high compared to the actual processing costs of the data within the sample. Therefore, it is desirable for a given total amount of data to have a smaller number of larger sample units.

The 17,000 samples currently in use by the USDA are each approximately 1 x 1 mile; the samples currently in use by LACIE are 5 x 6 miles. The USDA size was changed from approximately 2 x 2 miles to the present size in the 1950's because they empirically found that the information loss was slight compared to the reduction in sampling costs - particularly the costs of the ground enumerator. The current USDA size is also convenient because it often corresponds to the spacing of rural roads and thus makes the delineation of a sample easier. It is understood that the LACIE size was selected primarily because of the quantum limit presented by their data processing equipment.

The result of giving thought to each of the above considerations is the selection of the sample unit size at 4 x 4 miles each of this TOSS study. This size is the largest that can be efficiently and conveniently handled by the implementation system. This represents a first approximation of the cost minimization of the sample unit size versus sampling accuracy tradeoff.

### 3.4 CLOUD COVER IMPACT ANALYSIS

The presence of clouds between the spacecraft and the ground location to be measured preclude the obtaining of information at that location for that pass of the spacecraft. The seriousness of that missed observation to the overall success of the mission depends on the need for that particular observation and on the frequency with which it is missed. Some missions, for example the Inland Water Management application, require that observations be taken of very particular locations (for example the south slope of Mt. Lassen in the Shasta dam watershed). The nature of other missions, particularly those based on a sampling approach,

is such that the dependence on any particular observation is less. For a sampling type application it is often possible to select an equivalent observation or to aggregate the sample locations differently to allow for a missed observation. This report section will summarize the TOSS investigations into the effect of cloud cover; a more complete discussion is contained in Appendix K.

For the crop survey applications and the basic system implementation concept of TOSS, the cloud issue can be restated as a tradeoff between: the number of spacecraft passes, the number of sample locations attempted, and the timeliness of the observations. The number of passes versus timeliness trade is illustrated in Figure 3-8. In this figure, the height of the bars indicates the number of samples successfully obtained (cloud free) in the presence of a partially cloudy atmosphere. The two situations illustrated are for obtaining the same net number of samples (the bar heights total the same) in either a few number of passes (left hand case) or more passes (right hand case). The rightmost bar in each case represents the most recent pass and the adjoining bar the pass previous to that. The major difference being the greater number of allowable locations which must be provided for the left hand case. The significance lies in the larger number of sites which must be "ground truthed" or otherwise prepared prior to sampling. In other words the choice is either (1) a few passes covering a large number of acceptable sites or (2) more spacecraft passes but covering fewer prepared sites on each pass.

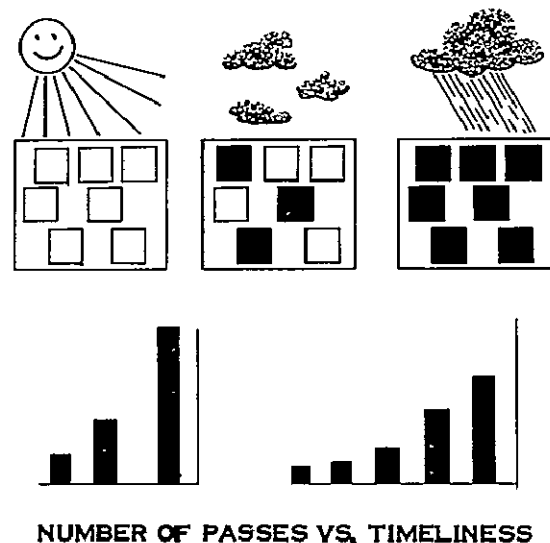


Figure 3-8. Cloud Cover - Passes Versus Timeliness Trade

The number of successful samples which can be expected as a percentage of those available versus the number of satellite overpasses is shown in Figure 3-9. These curves indicate the cumulative number of cloud free samples that will be obtained (selecting without replacement) at the end of the Nth pass. The curves are used by selecting the appropriate curve for the particular area or region of interest and then reading the percentage value of it corresponding to the desired number of passes. The appropriate curve to select is the one whose intercept corresponds to the  $P_1$  probability for the area of interest. The  $P_1$  probability is the probability of the area having less than 30% cloud cover. The  $P_1$  values for the areas shown in the figure correspond to the cloud cover conditions during the month of June at 10:00 AM local time.

Using data such as that from Figure 3-9 it is possible to compute the specific number of initial sample sites that will need to be attempted by the system. This initial number after being reduced by clouds will provide the net number of samples which is addressed in the sampling plan analysis. Note that the number of samples thus provided is the expected value with a one sigma confidence level (66 years out of 100).

One aspect of the foregoing discussion requires explicit treatment and that is the interchangeability of sample sites. The TOSS approach to extractive processing classification does not require the use of multitemporal spectral analysis (in the sense that three multispectral images of four bands each taken at three different times are processed as a twelve channel classification). This means that there is no particular need to sense the same sample site repeatedly. For the TOSS approach an equivalent sample, from the same sampling plan strata, may be measured instead of a cloud obscured one and there will be no decrease in the system performance. This concept of selecting an equivalent sample in lieu of a cloud covered one is referred to as the "floating sample" approach.

### 3.5 OVERALL SYSTEM PERFORMANCE ACCURACY

The preceding sections have addressed each of the five error components individually; this section will combine these five components into a total measurement error. This resulting total error,  $\sigma_M$  is the expected percentage error in the system's ability to measure the currently growing wheat acreage. The total error is expressed as:

$$\sigma_M = \sqrt{\sum_{i=1}^5 \sigma_i^2}$$

where  $\sigma_1$  = random component of classification error  
 $\sigma_2$  = random component of mensuration error  
 $\sigma_3$  = bias component of classification error  
 $\sigma_4$  = bias component of mensuration error  
 $\sigma_5$  = statistical sampling error

The  $\sigma_M$  thus obtained is the one sigma confidence (since each of the components was computed at one sigma) estimate of the expected value of the total error. The formulation of  $\sigma_M$  and some representative countries is illustrated in Figure 3-10. A complete tabulation of all of the errors analyzed in TOSS is shown in Table 3-7 for the MSS sensor and in Table 3-8 for the Thematic Mapper sensor. Each error component is shown in percentage terms.

A total of twelve cases or condition sets were formulated by varying the choice of sensor and number of samples. Each of these twelve cases was exercised through the Global Crop Survey economic model and the economic benefits to the U. S. thus computed. The twelve cases formulated are:



Case	Sensor	Samples For U. S.	Samples For Other 10 Countries	Remarks
1	MSS	1,000	4,000	
2	TM	1,000	4,000	
3	MSS	5,000	12,000	
4	TM	5,000	12,000	
5	MSS	10,000	18,000	
6	TM	10,000	18,000	
7	MSS	5,000	18,000	
8	TM	5,000	18,000	
9	MSS	5,000	18,000	No Capability for India
10	TM	5,000	18,000	No Capability for India
11	TM	10,000	25,000	
12	TM	$\alpha$	$\alpha$	No Sample Error

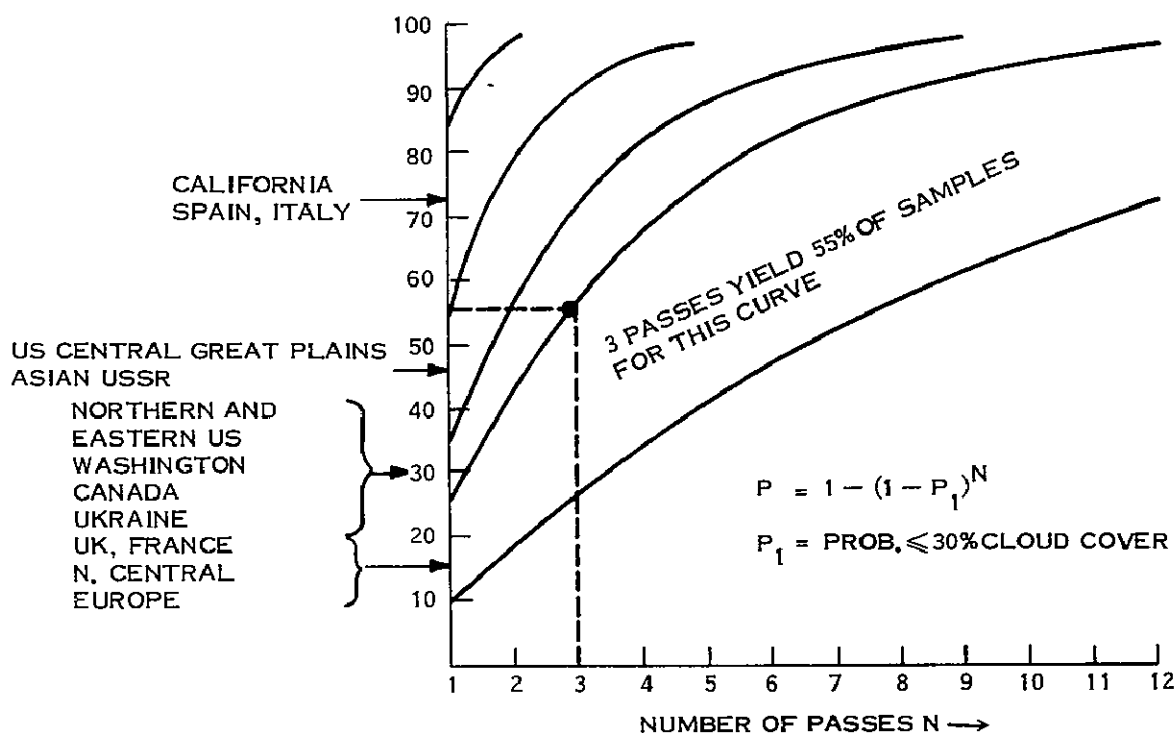


Figure 3-9. Average Percentage of Successful Observations vs. Number of Satellite Passes

It can be observed in these tables that the two random error components  $\sigma_1$  and  $\sigma_2$  decrease dramatically as the number of samples gets large. The two bias error components  $\sigma_3$  and  $\sigma_4$  are invariant to the number of samples, but are quite sensitive to the choice of sensor, MSS or TM.

The resulting total system measurement accuracy,  $\sigma_M$ , computed for these twelve cases and the corresponding economic benefits are summarized in Table 3-9.

Table 3-7. MSS Percentage Error Summary

Country	N = 4, 000		N = 12, 000		N = 18, 000			
	$\sigma_1$	$\sigma_2$	$\sigma_1$	$\sigma_2$	$\sigma_1$	$\sigma_2$	$\sigma_3$	$\sigma_4$
USSR	0	0	0	0	0	0	.07	.26
UK	.39	.71	.23	0	.18	0	13.81	23.89
CANADA	0	.21	0	0	0	0	2.60	5.52
ARGENTINA	.17	3.45	.10	.20	0	.16	2.75	1.24
AUSTRALIA	.22	.23	.13	0	.10	0	1.65	.13
SPAIN	.12	.42	0	0	0	0	4.09	3.34
FRANCE	.22	.37	.13	0	.10	0	3.30	23.89
ITALY	.25	.37	.14	0	.12	0	2.15	23.89
INDIA	0	0	0	0	0	0	8.35	8.88
SOUTH AFRICA	.15	.50	0	0	0	0	2.74	3.34

N is the number of sample units allocated to the ten countries.

Table 3-8. TM Percentage Error Summary

Country	N = 4, 000		N = 12, 000		N = 18, 000		N = 25, 000		$\sigma_3$	$\sigma_4$
	$\sigma_1$	$\sigma_2$	$\sigma_1$	$\sigma_2$	$\sigma_1$	$\sigma_2$	$\sigma_1$	$\sigma_2$		
USSR	0	0	0	0	0	0	0	0	.02	0
UK	0	0	0	0	0	0	0	0	1.73	8.06
CANADA	0	0	0	0	0	0	0	0	.78	.61
ARGENTINA	.13	0	0	0	0	0	0	0	.82	.15
AUSTRALIA	.17	0	0	0	0	0	0	0	.50	0
SPAIN	0	0	0	0	0	0	0	0	.38	.51
FRANCE	0	0	0	0	0	0	0	0	.41	8.06
ITALY	0	0	0	0	0	0	0	0	.27	8.06
INDIA	0	0	0	0	0	0	0	0	2.50	1.24
SOUTH AFRICA	0	0	0	0	0	0	0	0	.26	.51

N is the number of sample units allocated to the ten countries.

Table 3-9. Total System Measurement Accuracy

	TOSS Case Number											
	1	2	3	4	5	6	7	8	9	10	11	12
USA	.0826	.0668	.0555	.0302	.0515	.0216	.0555	.0302	.0555	.0302	.0216	.0045
USSR	.0383	.0382	.0223	.0221	.0182	.0180	.0182	.0180	.0182	.0180	.0150	-0-
UK	.4324	.3429	.3362	.2090	.3174	.1772	.3174	.1772	.3174	.1772	.1564	.0824
CANADA	.1174	.1008	.0841	.0588	.0772	.0483	.0772	.0483	.0772	.0483	.0412	.0099
ARGENTINA	.1734	.1677	.1012	.0970	.0844	.0792	.0844	.0792	.0844	.0792	.0675	.0083
AUSTRALIA	.1089	.1081	.0643	.0623	.0533	.0509	.0533	.0509	.0533	.0509	.0433	.0050
SPAIN	.2127	.2061	.1301	.1191	.1105	.0973	.1105	.0973	.1105	.0973	.0822	.0063
FRANCE	.2948	.1905	.2589	.1283	.2524	.1146	.2524	.1146	.2524	.1146	.1062	.0807
ITALY	.2926	.1860	.2587	.1259	.2526	.1321	.2526	.1321	.2526	.1321	.1048	.0806
INDIA	.1499	.0916	.1319	.0576	.1286	.0497	.1286	.0497	.9999	.9999	.0570	.0279
SOUTH AFRICA	.2497	.2460	.1503	.1441	.1253	.1177	.1253	.1177	.1253	.1177	.1002	.0057
ECONOMIC BENEFITS	224.8	238.0	320.2	353.8	391.2	428.8	388.2	425.4	374.4	397.6	438.9	490.7

Accuracy values tabularized are percentage errors expressed in decimal form (e.g., .0826 = 8.26%) economic benefits are millions of dollars per year of long term benefit to U.S.

### 3.6 ANALYSIS OF SYSTEM TIMELINESS

The economic benefits which accrue due to improved crop acreage estimates are sensitive to the timing of that information. The timing of the information consists of two factors which are defined as the update cycle and the timeliness. Update cycle is the time period between successive public releases or publications of the improved information (e.g., 30 days for a monthly publication cycle). Timeliness is defined as the staleness or age of the data, upon which the improved forecast is based, at the time of publication. The interaction of the timeliness parameter with the economic benefits is covered in more depth in Section 5. A visual summary of the sensitivity to timeliness for the U.S. Wheat Survey Case is illustrated in Figure 3-11. On this figure is shown the economic benefit curves for timeliness values of 30, 20, 10 and 0 days. Depending on the accuracy of the acreage measurement, the sensitivity to timeliness can be as great as tens of millions of dollars.

The value of update cycle used throughout the TOSS study was 30 days. This is consistent with the current USDA practice of publishing monthly crop forecasts. No attempt was made to vary this parameter.

$$\left( \begin{array}{c} \text{TOTAL} \\ \text{AREA} \\ \text{MEASUREMENT} \\ \text{ERROR} \end{array} \right) = F \left[ \left( \begin{array}{c} \text{RANDOM} \\ \text{CLASSIFICATION} \\ \text{ERROR} \end{array} \right), \left( \begin{array}{c} \text{RANDOM} \\ \text{MENSURATION} \\ \text{ERROR} \end{array} \right), \left( \begin{array}{c} \text{CLASSIFICATION} \\ \text{BIAS} \\ \text{ERROR} \end{array} \right), \left( \begin{array}{c} \text{MENSURATION} \\ \text{BIAS} \\ \text{ERROR} \end{array} \right), \left( \begin{array}{c} \text{STATISTICAL} \\ \text{SAMPLING} \\ \text{ERROR} \end{array} \right) \right]$$

$$\text{TOTAL AREA MEASUREMENT ERROR} = \sigma_M = \sqrt{\sum_{i=1}^5 \sigma_i^2}$$

COUNTRY	TOTAL ERROR, $\sigma_M$	ERROR COMPONENTS (% OF AREA)					COMMENT	
		RANDOM CLASS, $\sigma_1$	RANDOM MENSURATION, $\sigma_2$	CLASSIFIER BIAS, $\sigma_3$	MENSURATION BIAS, $\sigma_4$	SAMPLING $\sigma_5$		
US	2.16	.06	.04	.31	.33	2.11	TM	
	5.15	.16	.42	3.27	3.34	2.11	MSS	
USSR	1.8	0	0	.02	0	1.8	TM	LARGE FIELDS
	1.82	0	0	.07	.26	1.8	MSS	
FRANCE	11.46	0	0	.41	8.06	8.14	TM	SMALL FIELDS
	25.24	.10	0	3.30	23.89	8.14	MSS	

TABLE IS VALID ONLY FOR SPECIFIC VARIABLES USED

- RANDOM CLASSIFICATION AND MENSURATION ERRORS DECREASE WITH  $\frac{1}{\sqrt{N}}$
- EXPECTED VALUE OF BIAS ERRORS REMAINS SIGNIFICANT

Figure 3-10. Integrated Error Analysis

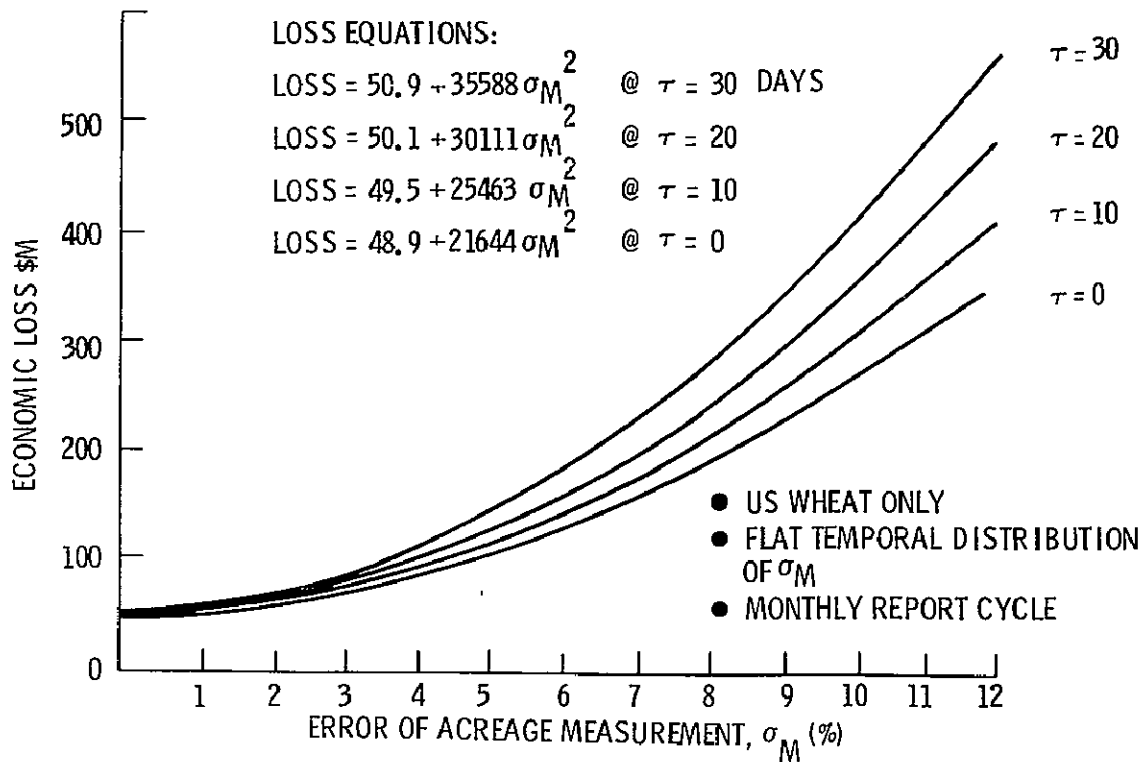


Figure 3-11. Sensitivity of Benefits to Timeliness

The derivation of the system timeliness parameters used in TOSS is discussed in depth in Section 4.3. The value used for the economic benefit computations of TOSS was 12.5 days. The timeliness parameter is computed by summing together all of the identified delays from the initial acquisition through to the final publication as is illustrated in Figure 3-12. The rationale behind each of the delay components values,  $\tau_i$ , is presented in Section 4.3. The result is that the overall system timeliness is 5 days plus one half of the spacecraft repeat cycle,  $\theta$ . For a repeat cycle of 15 days (instead of the current 18 for Landsat) which is the shortest single spacecraft repeat cycle consistent with the assumed drag and sensor coverage constraints, the corresponding timeliness parameter is 12.5 days.

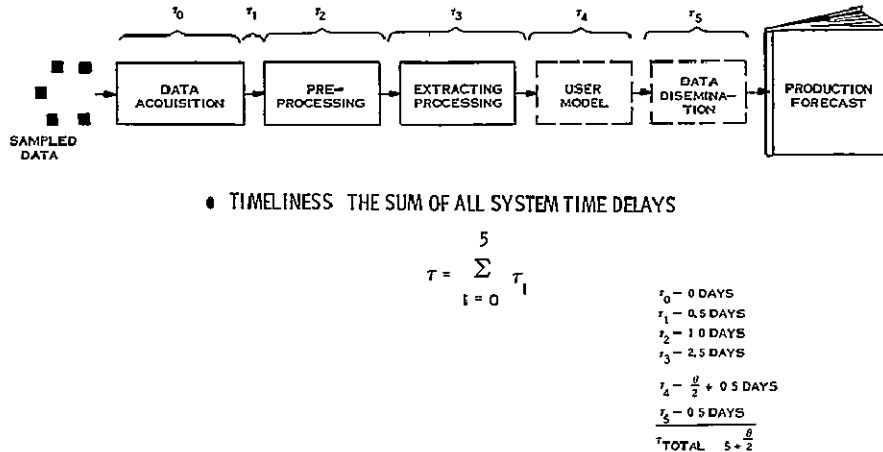


Figure 3-12. Computation of System Timeliness

### 3.7 FIELD SIZE ANALYSIS

Fields are the detectable spatial entities in the Earth's surface which are of importance to remotely-sensed crop inventory data. Their edges, or boundaries, contrast with surrounding land cover; the sharpness with which these boundaries can be detected bears directly on the accuracy with which acreage can be measured.\* The centers of the fields form the radiometric statistics (as individually detected radiance values) which permit discrimination of the field contents as one particular crop type from other land cover categories.

The dynamic interaction of the sensor's IFOV with the spatial entity of the field is central to the analysis and specification of system performance. The IFOV, as it is scanned in x and y directions and its detected output is sampled, produces a radio-geometric representation of the field which, for a given set of sensor characteristics, is strongly determined by several properties of the field: the field's size, its perimeter length, the multispectral contrast ratio between it and adjacent areas, the radiometric homogeneity of the field's center, and the spectral content and sharpness of the field's edges. The first two of these properties, field size and perimeter length were investigated as part of the TOSS and are discussed further in this section.

\*Although it is shown elsewhere in this report that high accuracy on an individual field is not necessarily a requirement if the residual error is unbiased and a sufficient number of fields is measured.

The distributions of field sizes and aspect ratios\* are the important functions, because the interaction with these parameters by the sensor's IFOV is decidedly non-linear. That is to say, since the errors associated with field size or aspect ratio are not linear functions, it is necessary to explicitly deal with the distribution of field sizes and aspect ratios in any meaningful system error analysis.

Overall "average" field sizes are not useful statistics. In particular, the portion of the total crop area contained in fields near the small end of the distribution area is of direct concern. It is in the small end of the field-size distribution where empirical and analytical data on the accuracy of multi-spectral analysis is the most uncertain. The approach used in the TOSS study was to compute explicitly the ever-increasing poorness of classification and mensuration accuracy with decreasing field size down to a point where the fields become so small that confidence in the analysis is essentially nil. The capability of the remote sensor to operate below this point was assumed to be zero. The point at which the confidence in the ability of a scanner to classify and mensurate became too low was taken to be where the field is equal in size to sixteen IFOV's.\*\* This cutoff point was chosen because it represents the field size (of a square field) for which:

(1) there are zero center field IFOV's, assuming a double row of border IFOV's in all four sides, and (2) there will be at least four IFOV's along the field border with which to identify and locate the field boundary. Figure 3-13 illustrates the cutoff points for the TM and MSS on an aggregated U.S. field size distribution where the IFOV sizes were 30 and 80 meters square, respectively. For the TOSS analysis, accuracies below the cutoff point were computed as though no remotely sensed information on small fields were available and that historical differences in variation of production between large and small fields were used instead of remotely sensed data. Refer to Section 3.2.2.2 for a discussion of the computation of this error component. The remainder of this section will

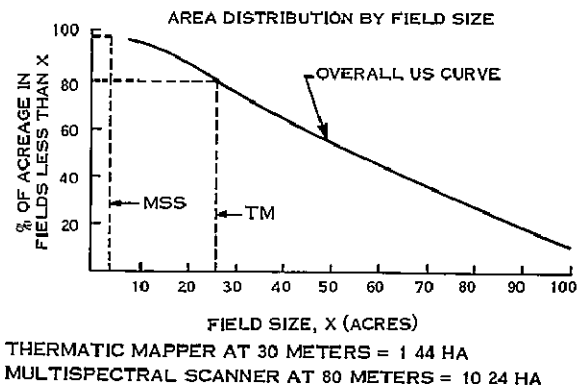


Figure 3-13. Sixteen IFOV Cutoff Points for U.S. Fields

\*\* It should be noted that the cutoff size is specified as an integer number of IFOV's, not pixels. This is consistent with the information theoretic approach taken throughout the TOSS analysis, in that proper tailoring of the system MTF to the optical IFOV will produce a certain amount of information in the data which is not modified by over or undersampling. The peculiarity of Landsat pixels, which are not square and are oversampled, is not a consideration here.

\*Aspect ratio is taken here to be length-to-width ratio; a measure of the squareness of the field, or the length of the perimeter for a field of a given area.

discuss the determination of the field size distributions themselves and the judgements which went into their preparation.

No statistical agencies in the U. S. nor in other countries make a practice of publishing field size distributions. Other studies have attempted to circumvent this problem by resorting to the use of surrogate data -- principally, data on the sizes of holdings. Clearly however, data pertaining to the distribution of holding sizes does not address the proper system question, and their use is likely to result in the derivation of improper conclusions, as illustrated in Figure 3-14.

Recognizing this fact, the TERSSE study team opted to follow a more difficult, but potentially more rewarding type of approach -- that of deriving field size data from image analysis and combining that analysis with the limited but useful results from other investigations. Appendix J describes the effort undertaken to produce the field size distributions listed in Table 3-10. Data were compiled for field size distribution both in terms of number of fields and in terms of percent of total area. The former was used to obtain the median field above the cutoff for use in the classifier model; the latter was used to determine the percentage of area for a given region or country which would not be measurable with a given sensor. Examples of the two types of distribution are illustrated in Figures 3-15 and 3-16. Field aspect ratios were also measured from S190B data by the TOSS study team as reported in Appendix J. From these aspect ratio distributions, it can be observed that the largest number of fields are contained in the low aspect (closer to square) categories. Throughout the TOSS analysis, square fields were used exclusively. From the data of Appendix J it would be possible to perform more refined computations, but the impact on total system accuracy will be negligible.

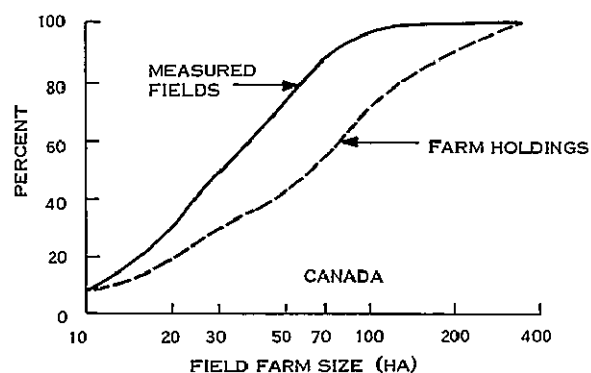


Figure 3-14. Comparison of Measured Field Size with Farm Holdings

Three points concerning the TOSS field size analysis will be recognized from the foregoing discussion and an inspection of Appendix J: first, this collection of empirical field size data represents the most complete known body of such data yet assembled. As such, it can form the basis for further studies and for addition of new data as it becomes available. Second, the distributions do not discriminate by the type of crop contained in the field; wheat fields and corn fields are represented by the same distribution. For wheat fields, the available data from Von Steen in Appendix J indicates that this might not be a bad approximation.

Third, while adequate for the TOSS analysis, even this TOSS collection of field size data is meager. Much remains to be learned about the effects upon system design of farming practices in several major grain producing countries as they affect field sizes and the variations in production from small fields.

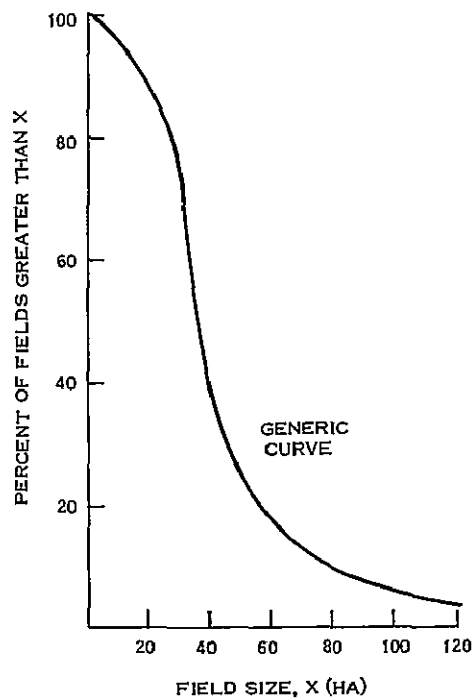


Figure 3-15. Field Size Histogram

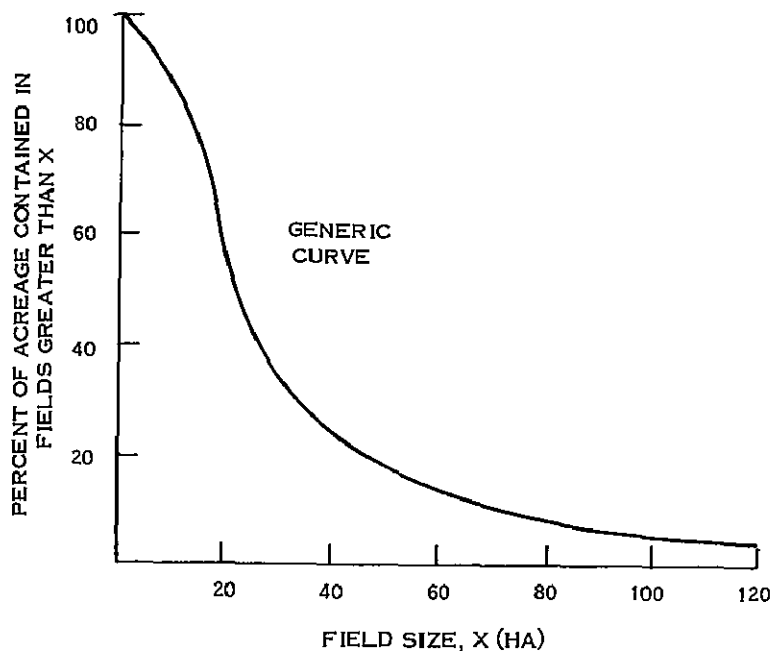


Figure 3-16. Field Size Area Distribution



Table 3-10. Summary of TOSS Field Size Distributions

Appendix J Figure No.	Where	Source	Remarks
1	CANADA (S. MANITOBA)	S190B	ALL FIELDS
1	CANADA (ONTARIO)	S190B	ALL FIELDS
1	FRANCE	S190B	ALL FIELDS
1	ARGENTINA	S190B	ALL FIELDS
2	BRAZIL	S190B	ALL FIELDS
2	MEXICO	S190B	ALL FIELDS
2	NEBRASKA-KANSAS	S190B	ALL FIELDS
2	MONTANA	S190B	ALL FIELDS
3	FRANCE	S190B	ALL FIELDS
4	ARGENTINA	S190B	ALL FIELDS
5	SOUTH DAKOTA	S190B	ALL FIELDS
6	THAILAND	S190B	ALL FIELDS
7	CANADA	S190B	ALL FIELDS
8	MEXICO	S190B	ALL FIELDS
9	BRAZIL	S190B	ALL FIELDS
10	FRANCE	S190B	ALL FIELDS
11	ARGENTINA	S190B	ALL FIELDS
12	SOUTH DAKOTA	S190B	ALL FIELDS
13	THAILAND	S190B	ALL FIELDS
14	CANADA	S190B	ALL FIELDS
15	MEXICO	S190B	ALL FIELDS
16	BRAZIL	S190B	ALL FIELDS
17	SALTON SEA, CAL.	S190B	ALL FIELDS
20	SOUTH DAKOTA, CRD NO. 6	VON STEEN	CORN
21	SOUTH DAKOTA, CRD NO. 6	VON STEEN	OATS
22	SOUTH DAKOTA, CRD NO. 6	VON STEEN	SOYBEANS
23	SOUTH DAKOTA, CRD NO. 6	VON STEEN	SPRING WHEAT
24	SOUTH DAKOTA, CRD NO. 6	VON STEEN	BARLEY
25	SOUTH DAKOTA, CRD NO. 6	VON STEEN	WINTER WHEAT

Table 3-10. Summary of TOSS Field Size Distributions (Continued)

Appendix J Figure No.	Where	Source	Remarks
26	SOUTH DAKOTA, CRD NO. 6	VON STEEN	TOTAL WHEAT
27	SOUTH DAKOTA, CRD NO. 6	VON STEEN	ALL CROPS
28	KANSAS, CRD NO. 7	VON STEEN	CORN
29	KANSAS, CRD NO. 7	VON STEEN	OATS
30	KANSAS, CRD NO. 7	VON STEEN	BARLEY
31	KANSAS, CRD NO. 7	VON STEEN	WINTER WHEAT
32	KANSAS, CRD NO. 7	VON STEEN	RYE
33	KANSAS, CRD NO. 7	VON STEEN	ALL CROPS
34	MISSOURI, CRD NO. 9	VON STEEN	BARLEY
35	MISSOURI, CRD NO. 9	VON STEEN	RYE
36	MISSOURI, CRD NO. 9	VON STEEN	CORN
37	MISSOURI, CRD NO. 9	VON STEEN	OATS
38	MISSOURI, CRD NO. 9	VON STEEN	WINTER WHEAT
39	MISSOURI, CRD NO. 9	VON STEEN	SOYBEANS
40	MISSOURI, CRD NO. 9	VON STEEN	ALL CROPS
41	S. C. IDAHO	VON STEEN	CORN
42	S. C. IDAHO	VON STEEN	OATS
43	S. C. IDAHO	VON STEEN	BARLEY
44	S. C. IDAHO	VON STEEN	WINTER WHEAT
45	S. C. IDAHO	VON STEEN	SPRING WHEAT

Table 3-10. Summary of TOSS Field Size Distributions (Continued)

Appendix J Figure No.	Where	Source	Remarks
46	S. C. IDAHO	VON STEEN	TOTAL WHEAT
47	S. C. IDAHO	VON STEEN	ALL CROPS
48	WILLIAMS, N. DAKOTA	LAND- SAT	ALL FIELDS
49	WILLIAMS, N. DAKOTA	LAND- SAT	WHEAT
50	WILLIAMS, N. DAKOTA	LAND- SAT	ALL NON-WHEAT FIELDS
51	MELFORT, SASK	LAND- SAT	ALL FIELDS
52	MELFORT, SASK	LAND- SAT	WHEAT
53	LEE, ILL.	CITARS	ALL FIELDS

## **SECTION 4**

### **SYSTEM DESIGN**

## SECTION 4

### SYSTEM DESIGN

The Crop Inventory Satellite System must meet certain performance requirements in order that the economic benefits forecasted to result from its use are in fact realized. The system must be designed to meet these performance requirements in a cost-effective way. It must use the proper mix of new technology, where it is less expensive or more powerful, and the experience from today's systems. And it must be designed to perform its mission dependably in order that its information output be useful and used.

In addition to its Crop Inventory operational requirements a second set of requirements must be met by this Same Earth Resources Satellite System; those of providing tape and film imagery to a large number of R&D and other operational users in many countries whose demand for such information has been established by the early Landsat flights. These users must be served while not seriously compromising the major mission of Crop Inventory. But neither their economic and social benefit from the system nor their importance to its justification should be underestimated.

This section will describe the Crop Inventory System designed to TOSS and will illustrate the power of TOSS as a total system analysis tool through its use in three key system level tradeoffs.

#### 4.1 CROP INVENTORY SYSTEM OVERVIEW

The resultant system, illustrated in Figures 4-1 and 4-2 contains two major segments: a common or multi-mission segment and the mission-dedicated segment peculiar to the Crop Inventory mission. Data gathering by the polar satellite(s), its relay via TDRS to White Sands, its reformatting and retransmission via DOMSAT to the preprocessing center, and the radiometric correction portion of the preprocessing itself are all multi-mission, or common steps, in the data flow process.

The break between the Crop Inventory mission-dedicated segment and the multi-mission flow occurs before geometric correction because of the major difference in such processing needed by each particular application system, in this case the crop inventory system. The Crop Inventory system processes data in increments of 4 x 4 mi. arrays - only minor geometric correction\* is needed on this area and the savings in time, equipment cost, and radiometric accuracy are significant if only limited geometric correction is performed. Full geometric correction, on the other hand, is a requirement of an ever-increasing number of other users and the provision of this degree of correction, involving full resampling of the data, should be provided in their application-peculiar systems.

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\* Displacement (x and y) and rotation of the entire 4 x 4 mile array is sufficient; resampling of the array to relocate individual pixels is not required to meet the acreage accuracy requirements of the system.

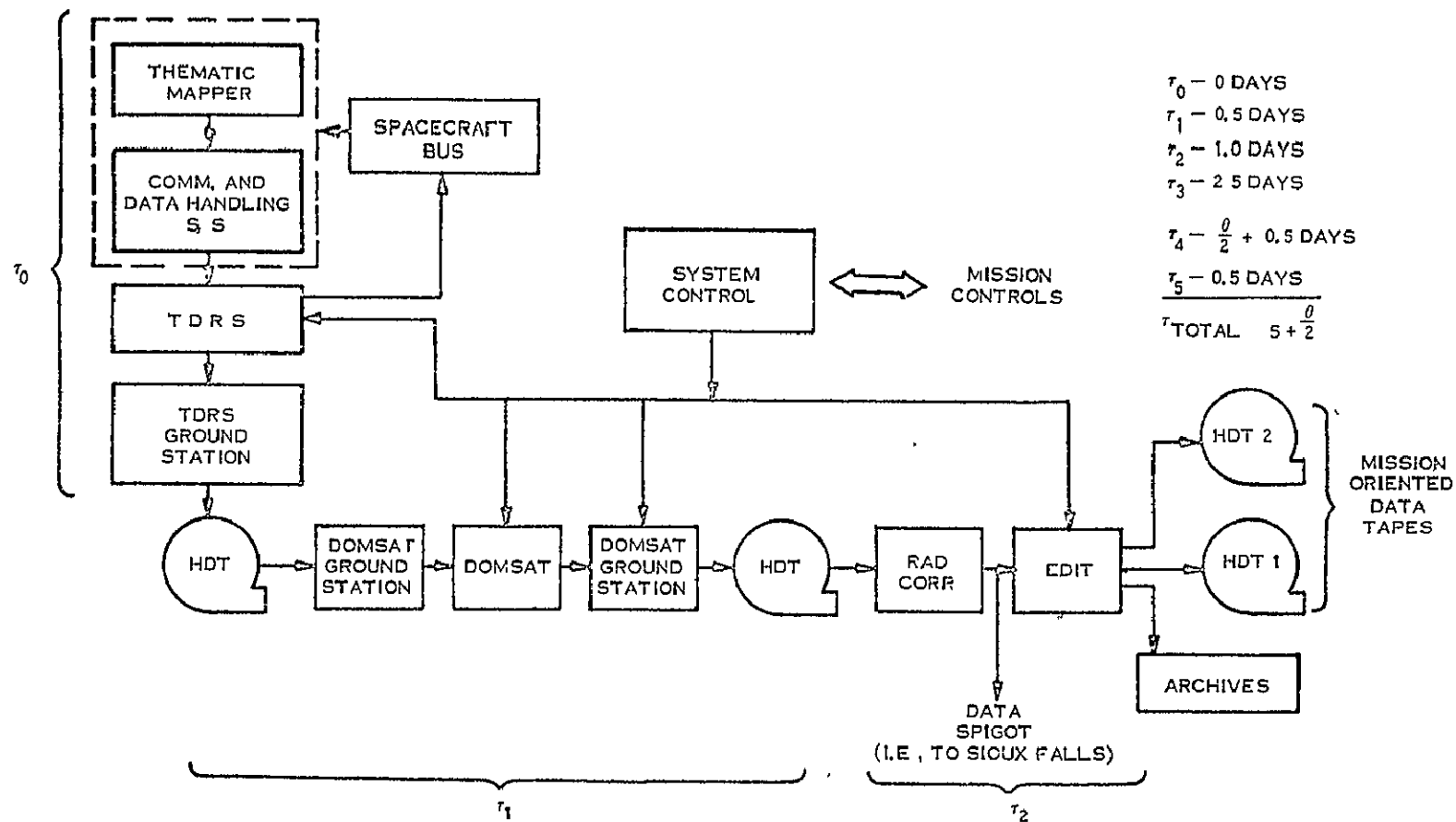


Figure 4-1. System Architecture (Multi-Mission Common)

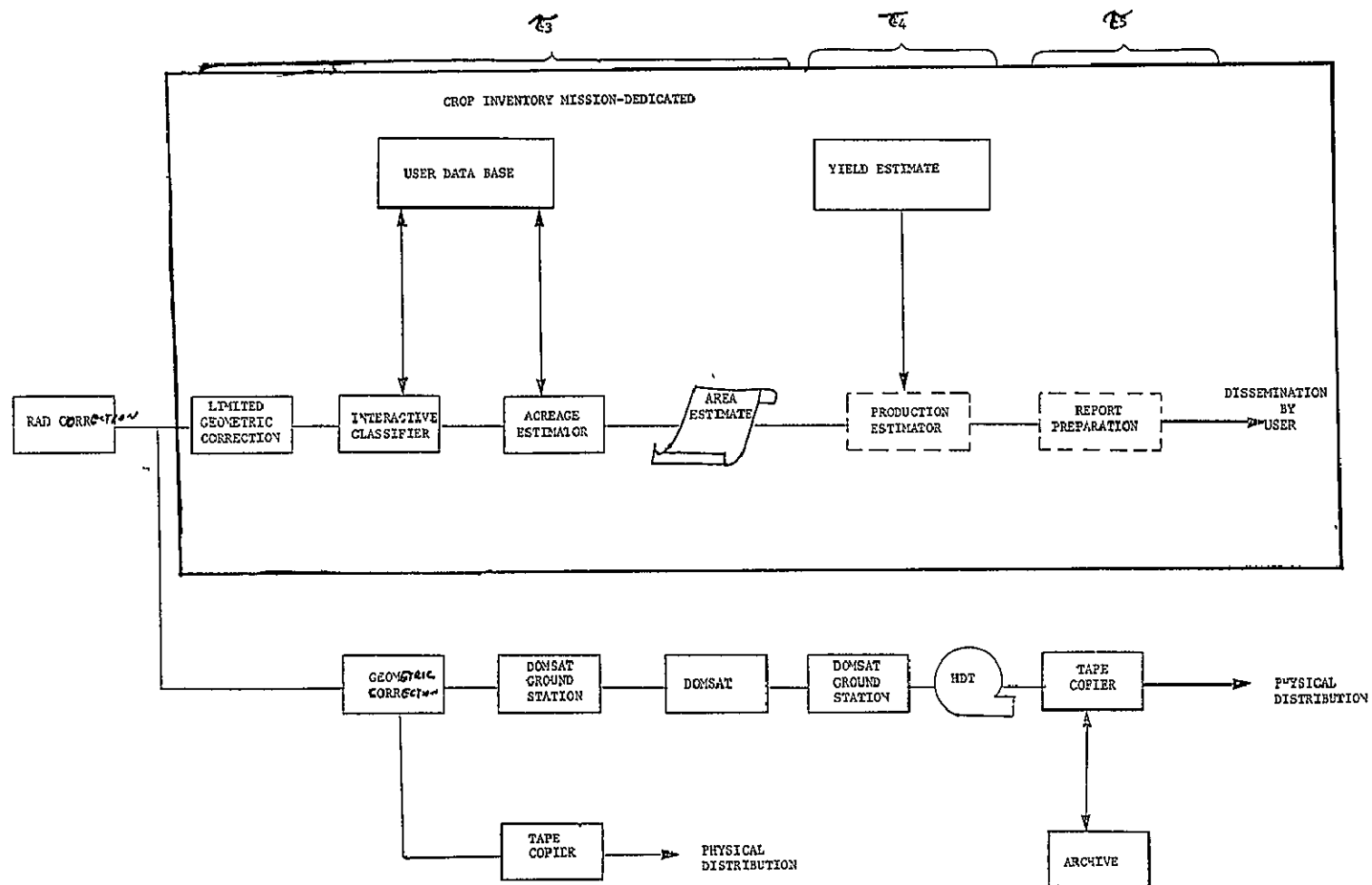


Figure 4-2. System Architecture (Mission Dedicated)

The completion of the bifurcated flow is, in the case of the Crop Inventory mission, the extraction of sample segments, classification and identification of agricultural fields by an interactive classifier, and operation of the acreage estimation processor to remove biases and solve statistical relationships. A key feature of this process is the inter-connection of the extractive processing and acreage estimation processor with a user (USDA/SRS) data base.

#### 4.2 MAJOR ELEMENTS OF CROP INVENTORY SYSTEM

The previous section gave a brief overview of the Crop Inventory System. The present section will single out certain major system elements for a more detailed description. One of the purposes of this closer examination is to show that the Crop Inventory System can be particularized and therefore is realizable.

The following subsections contain a description of the following major system elements:

- Thematic Mapper
- Spacecraft
- TDRSS utilization
- DOMSAT utilization
- Data Preprocessing
- Extractive Processing (Mensuration and Classification)

##### 4.2.1 THEMATIC MAPPER SENSOR

The Thematic Mapper (TM) is a second generation earth resources multispectral scanner having significantly advanced characteristics over the Multispectral Scanner (MSS) currently used in Landsat 1 and 2. Specifications for TM were taken from the Final Report of the Landsat-D Thematic Mapper Technical Working Group, which met at Purdue University in early summer of 1975. Appendix N contains the Introduction, Recommendations and Conclusions from that report.

TM is a seven band multispectral scanner with six bands in the visible/near infrared and one in the thermal infrared. The spectral band locations are:

TM Band	Wavelength Band
1	0.45 - 0.52 um
2	0.52 - 0.60
3	0.63 - 0.69
4	0.74 - 0.80
5	0.80 - 0.91
6	1.55 - 1.75
7	10.40 - 12.50



If a seven band sensor is not feasible, the Working Group recommended that band 1 be deleted. These bands are narrower than, and displaced from, those of the MSS, whose four bands are located.

MSS Band	Wavelength Band
1	0.5 - 0.6 $\mu$ m
2	0.6 - 0.7
3	0.7 - 0.8
4	0.8 - 1.1

The noise equivalent ground reflectance, commonly called  $NE\Delta\rho$  (noise equivalent delta reflectance) is 0.005 for bands 1 thru 6. The noise equivalent ground temperature difference, commonly called  $NE\Delta T$  (noise equivalent delta temperature) is 0.5<sup>o</sup>K for bands 6 and 7.

The recommendations for dynamic range were made in terms of ground reflectance for saturation. They are:

Band	Ground Reflection for Saturation
1	20 %
2	58
3	53
4	75
5	75
6	50

The dynamic range for the thermal infrared band, band 7, is 270 to 330<sup>o</sup>K.

For bands 1 thru 6 the instantaneous field of view (IFOV), which is a measure of spatial resolution, was selected by the Working Group to be 30-40 meters with a recommended design goal of 30 meters. Because of scanner design constraints the thermal band IFOV was chosen to be 120 meters. 30 meters was used by TOSS for all seven bands in its analysis.

A very important value for the system design is the TM data rate. This depends on the sampling rate per IFOV, the IFOV size, the swath width (and whether the scan is conical or linear) and the number of bits per sample. The Purdue TM Working Group made a point of not specifying the sampling rate; they said further study should be made to determine an optimum sampling scheme for the total system including data acquisition and processing.

Data rates of 15 Mbps for TM were used for TOSS. These high data rates and need for real time data transmission from the User S/C to the earth indicate the need for using the TDRSS (Tracking and Data Relay Satellite System). Before discussing the TDRSS certain requirements on the S/C will be addressed.

#### 4.2.2 SPACECRAFT

The primary effect of TOSS on the S/C is the alteration of its repeat cycle from the 18 days, used by the current Landsats, to 15 days. The resulting orbit change had also to satisfy the desire to retain the swath width of 185 km (100 nm) with approximately 3 percent sidelap coverage at the equator.

Previous General Electric studies were used to select an appropriate orbit. Mission orbit analysis from these studies eliminated orbits below 555 km (300 nm) because of excessive fuel consumption to overcome atmospheric drag, and above 925 km (500 nm) because of the severe design requirements on the sensor optics.

The resulting candidate orbit satisfying the necessary requirements is a 590 km altitude orbit. This orbit does have a 15 day repeat cycle and a 185 km (100 nm) swath width with 3 percent sidelap at the equator. It has approximately a 96 min. orbital period, consecutive swathing orbits, and 224 revolutions/cycle.

The data transmission rate of 100 Mbps from the S/C to the earth via the TDRS (Tracking and Data Relay Satellite) introduces the need for a modification of the current Landsat S/C communication link to incorporate features required for functioning with the TDRS transponders. Typically, the 100 MBPS TM data rate will require 11.2 watts Ku-band output from a 3.81 meter diameter antenna.

#### 4.2.3 TDRSS/DOMSAT UTILIZATION

The TOSS Crop Inventory Mission will require the real time transmission at high data rates (100 MPBs) from a TM based S/C gathering multispectral crop data on a world wide scale. A data handling problem of this nature and scope can be performed by employing a TDRSS to transfer data from the TM S/C to the earth and a Domsat (Domestic Communications Satellite) to distribute the data to the various users on the earth.

The TOSS utilization of TDRSS is architecturally shown as indicated in Figure 4-3. The TDRSS is required for real-time wideband data transfer from the S/C to a ground station; and the Domsat is necessary (see tradeoff study in Section 4.4.2) to relay wideband data from the White Sands TDRSS Ground Station to distant processing and user stations. (Ground transmission systems limited to 1 to 2 Mbps are not adequate to handle the wideband data for TOSS). Brief general information on some of the related programs is given below.

TDRSS: The system will use two synchronous satellites to receive data from low altitude satellites, and relay the data to a ground station at White Sands, N.M. as shown in Figure 4-4. Data from user satellites may be

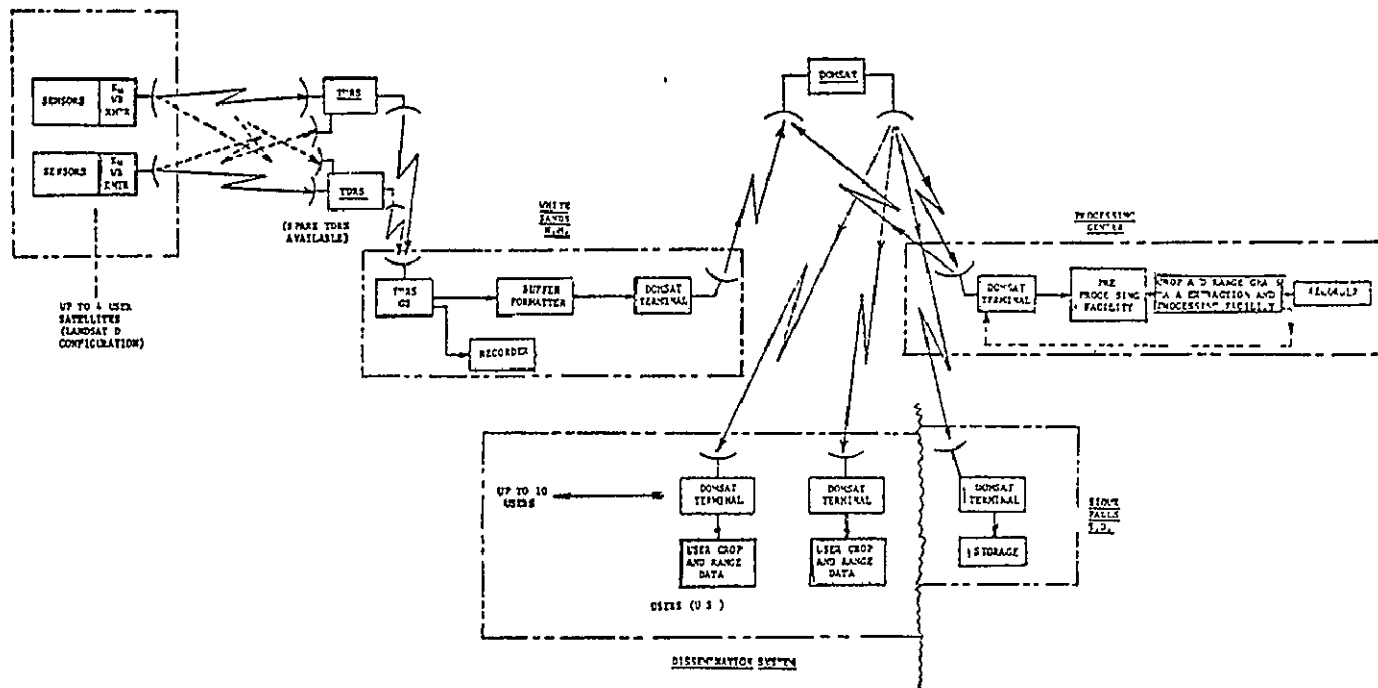


Figure 4-3, Top Level Dissemination System

transferred on either S-band or Ku-band links, but only the latter are sufficiently wideband for the TOSS purpose. The TDRS satellites are located at about  $40^{\circ}\text{W}$  and  $170^{\circ}\text{W}$ , which results in a small area not covered (see tradeoff study in Section 4.4.3) by either, centered on  $75^{\circ}\text{E}$ ; the extent of the above varies with user S/C altitude, and becomes essentially zero above 1200 km. The TDRS Ku-band transponder follows an acquisition procedure with the user S/C, each being required to track the other. Data are subsequently transferred to the ground station over a Ku-band link; each TDRS has a separate ground receiving subsystem. The data are reformatted and transmitted via the NASCON interface to a nearby Domsat ground station. The TDRSS is also capable of transmitting commands to the user S/C.

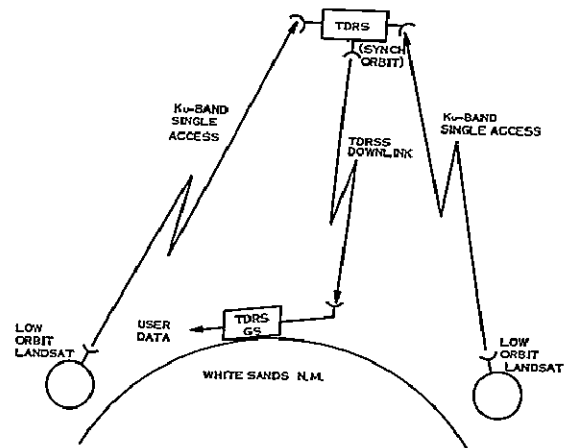


Figure 4-4. Landsat S/C and TDRSS Data Transfer Configuration for TOSS

The TDRSS ground system can handle "single access" data from three TDRS's simultaneously (two active, one spare), and can operate with any combination of up to six 100 Mbps channels, or one 300 Mbps channel plus five 100 Mbps channels. The TOSS system will use the two active satellites and will have an option of up to four 100 Mbps channels, or one 300 Mbps channel plus three 100 Mbps channels.

Domsat. The Domsat B is used as a typical communications link for the wideband data since overland links are limited at the TDRSS NASCOM interface to 1 to 2 Mbps; the Domsat can relay as many as 48 36-MHz channels, 24 each on c- and Ku-bands. For the purpose of this study, the data are assumed to be of the order of 75 MHz wide (subject to some adjustment and depending on the TDRSS specification for the 100 Mbps channels). The individual Domsat channels are up to 36 MHz wide, so typically the data would be reformatted from the 75+ MHz width to two or three 36-MHz width channels. The data can be relayed either at C-band, as is used in most currently established communications links, or may be at Ku-band where equivalent channels are to be established. The general capabilities of the Domsat indicate it is adequate to handle the TOSS data as outlined previously. The proposed configuration will cover the United States, including Alaska and Hawaii. The procedure indicated by Figure 2-1 includes first a transmission of the data to a Processing Center where certain data may be extracted, processed, and stored. The processed data may be reformatted and retransmitted, probably through the same Domsat, to user ground stations distributed throughout the United States (and possibly elsewhere if required).

A more complete discussion of the TOSS utilization of TDRSS and Domsat is presented in Appendix O.

#### 4.2.4 DATA PREPROCESSING

Preprocessing for the Crop Inventory Mission includes the need to perform radiometric and certain geometric corrections to the raw data. These corrections for TM data will likely be of same kind and/or similar to those presently required for Landsat 1 and 2.

Radiometric errors from the present Landsats, with MSS as the sensor, manifest themselves in images as banding in the along-scan direction. This kind of error, or noise is common in MSS type sensors, which have several detectors (six in MSS) in each band scanning parallel, adjacent lines on the ground. Since it is not possible to match the detector responsivities perfectly, the resultant image shows bands of periodic light and dark scan lines. In Landsat 1 this distortion can be as great as ten quantum levels. To normalize the detector outputs, relative calibrations are performed at the end of every few scans.

Geometric distortions arise both from random fluctuation in sensor operation and from predictable systematic sources. Examples of the former include spacecraft attitude, altitude and velocity fluctuations, and non--earth curvature effects. The systematic error sources can easily be modeled. The errors resulting from S/C attitude variations can be modeled if the vehicle has an attitude measurement system, as Landsat does. If all the error sources can be modeled, a geometric correction function can be computed. Otherwise, a correction function can be generated by correlation of ground control points (GCP). Either way, the geometric correction procedure consists of applying the (two-dimensional) correction function to the image to perform a "rubber-sheet" correction. The corrected image is then resampled on a regular orthogonal grid to produce the final corrected image. When the error source model technique is used, GCP's are usually also employed for final "tweaking".

A Master Data Processing System (MDP) is presently being planned by NASA to perform this type of radiometric and geometric correction on Landsat images as well as digital images from future sensors. The pertinent specifications for MDP are:

Throughput	$10^{11}$ bits/day (500 ERTS MSS Scenes/day)
Radiometric correction	2 quantum levels over full range
Geometric correction with GCP	1 pixel 90% of the time
Temporal registration	0.5 pixel 90% of the time

From the development of TOSS preprocessing requirements presented in Appendix I certain provisioned conclusions can be made: The Crop Inventory Missions will require radiometric correction of the highest degree of accuracy possible. In particular the resampling requirement, needed for fully corrected image, is not required for the Crop Inventory Mission.

#### 4.2.5 EXTRACTIVE PROCESSING

The extractive processing for the Crop Inventory Mission has the task of transforming the TM - gathered agricultural data, which has been relayed from the S/C via TDRS and Domsat and preprocessed, into crop acreage inventory values. Clearly this is the most important element of the entire system. The extractive processor is the only element of the system design that involves technology implementation development.

The extractive processing must first segregate the area of each sampling unit into homogeneous radiance regions thereby singling out a set of spatial regions as candidate agricultural fields. With this essential first operation accomplished there remain the two parallel operations of area mensuration and crop classification. The requirements which the TOSS extraction process must meet are summarized as follows:

- It must accept and classify up to 50,000 sample segments of 4 x 4 miles in size in a thirty-day period with two eight-hour shifts, for five days per week.
- It must achieve a classification accuracy on such data described in Section for the range of field sized of 1.4 HA and larger. In particular, the accuracy of assigning crop classes to feature - space clusters shall be 98 percent or greater.
- It must be capable of rapidly interfacing with a computer data base which will provide the classifier with such inputs as a priori probabilities of crop density and presumed or truthed individual field contact.
- It must permit optimal utilization of human - interactive technique and judgment to maximize throughput - rates.
- It must be capable of providing its individual field results, radiance statistics, and a posteriori probabilities of crop density - back to the previously mentioned computer data base.

These requirements suggest an extractive processor design which is different from any currently - implemented system but which can be built from today's knowledge. The processor will have multiple-operator displays which permit rapid human/machine interaction in both the conventional spatial domain and in feature or spectral space. The classifier will perform the initial classification in an unsupervised (or semi-supervised) mode making use of spatial feature dimensions (e.g., field boundaries) as well as radiance feature dimensions (spectral band information). Interaction by operators following the initial classification, when combined with the rapid callup and display of exogenous truth data, is foreseen as the means to reduce operator costs at the high throughputs required.

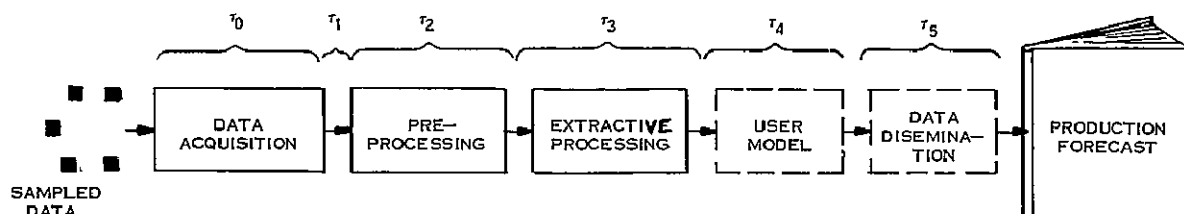
Significant hardware, software, and operations analysis work remains to be done to produce such a classifier. But a step forward of this magnitude will markedly enhance the cost-effectiveness of the Crop Inventory System by lowering its operational costs.

### 4.3 TIMELINESS

The system characteristic of timeliness is defined as the time interval between the acquisition of data and its final release as published information. As such, it is a measure of the age or oldness of the data at the time it is published and released to the user who will use it in his resource management function. Section 3.6 discussed the use of the timeliness parameter in the overall OTSS analysis and the sensitivity of the economic benefits to timeliness. This section will discuss each of the components which together comprise the timeliness parameter.

Figure 4-5 shows the development of timeliness to be the sum of six individual time delay components,  $\tau_i$ ,  $i = 0$  to 5. The first delay,  $\tau_0$ , spans the interval from initial acquisition, through the spacecraft, through the Tracking and Data Relay Satellite (TDRS), to the TDRS ground station at White Sands, New Mexico where the data stream is recorded on high speed, high density digital tapes (HDT's). Because of the use of TDRS, this process occurs in real time and the associated delay is zero.

The second delay,  $\tau_1$ , covers the interval from receipt of data at the TDRS White Sands ground station through the data transfer process to the point at which the data is received at the preprocessing facility (assumed to be located in the Washington, D.C. area). The TOSS implementation approach will utilize a domestic



● TIMELINESS THE SUM OF ALL SYSTEM TIME DELAYS

$$\tau = \sum_{i=0}^5 \tau_i$$

$$\begin{aligned}
 \tau_0 &= 0 \text{ DAYS} \\
 \tau_1 &= 0.5 \text{ DAYS} \\
 \tau_2 &= 1.0 \text{ DAYS} \\
 \tau_3 &= 2.5 \text{ DAYS} \\
 \tau_4 &= \frac{\theta}{2} + 0.5 \text{ DAYS} \\
 \tau_5 &= 0.5 \text{ DAYS} \\
 \hline
 \tau_{\text{TOTAL}} &= 5 + \frac{\theta}{2}
 \end{aligned}$$

Figure 4-5. Development of Timeliness Parameter

communications satellite, Domsat, to accomplish this data transfer. The actual transfer itself will be near instantaneous; however, time is required to buffer the data in order to take advantage of its discontinuities. The data stream originating at the Thematic Mapper is approximately 100 Mbps during the intervals when the sensor is on; however, it will only be on during daylight passes over the world's land areas. This results in a high speed but discontinuous data stream whose average data rate is significantly lower. The data stream will be buffered at White Sands to take advantage of the lower average rate by playing back the high speed recordings over Domsat at the lower rate. A time interval of one half day has been allocated to  $\tau_1$  for this buffering process and the necessary logging and handling of the digital tapes.

The third delay component,  $\tau_2$ , provides for the radiometric preprocessing and data selection (edit) functions. The implementation of the radiometric correction will be via the Master Data Processor (MDP) facility (currently under procurement by NASA/GSFC) which has the capability to process the entire data load in real time. The edit function involves the extraction of the required sample sites from the data stream. The potential sites are identified by longitude and latitude in a computer storage; the potential sites are automatically located and extracted from the data flow and an assessment made as to the closed cover extent. The resulting selected sample sites are recorded on a high density tape for further processing by the crop inventory dedicated portion of the system. A total of one day has been allocated to these functions for the processing, tape handling, logging, and annotation of the data.

The fourth delay component,  $\tau_3$ , covers the crop inventory unique preprocessing function and the entire extractive processing function up through the point where total estimates are made of the growing crop acreage. The degree of geometric preprocessing required for the crop inventory mission (without multitemporal analysis) is relatively minor; full resampling of the pixels is not necessary; simple coefficients of translation and rotation will be adequate. The extractive classifier will be a highly automated man-machine interactive arrangement where all of the routine steps are automated on a high speed special purpose processor. The classifier will be directly tied into the USDA data base for its ground truth requirements and will maintain a temporal record of each sample location. The classifier will attempt an unsupervised clustering of the spectral data and display its spatial and spectral results to a highly skilled agricultural specialist for verification and/or correction. The measured results from each sample are then statistically aggregated to form the total area estimate. A total time delay of three and one half days has been allocated for this process.

The fifth delay component,  $\tau_4$ , covers the formulation of the production (bushels or tons) estimate. The production estimate is formed by combining the area estimate with the exogenously obtained yield estimates. This process has been allocated one half a day. In addition to actually forming the production estimate, this delay component contains the acknowledgement of the need for full coverage. The spacecraft will cover the world by taking swaths of data (100 miles wide) which begin to repeat every repeat cycle,  $\theta$ . To get full coverage thus takes  $\theta$  days and the average age of the full data at any particular point is  $\theta/2$ . Therefore, the delay component  $\tau_4$  has a total value of  $0.5 + \frac{\theta}{2}$  days.



The sixth and final delay component,  $\tau_5$ , covers the actual dissemination of the crop production estimate to the operational user. Once the estimate has been computed, in the previous steps, what remains is the review of this estimate and its public release. The review and release process for TOSS is essentially the same as the process currently in use by the USDA with a lockup procedure and public release at a specific time. This delay component has been allocated one half day.

The total time delay is the sum of the above six components. This summation is:

$$\begin{aligned}
 \tau_0 &= 0 \text{ days} \\
 \tau_1 &= 0.5 \text{ days} \\
 \tau_2 &= 1.0 \text{ days} \\
 \tau_3 &= 2.5 \text{ days} \\
 \tau_4 &= \frac{\theta}{2} + 0.5 \text{ days} \\
 \tau_5 &= 0.5 \text{ days} \\
 \hline
 \tau_{\text{Total}} &= 5 + \frac{\theta}{2} \text{ days}
 \end{aligned}$$

A repeat cycle of  $\theta = 15$  days was chosen for the baseline system. Mission orbit analysis based on previous GE studies eliminated orbits below 300 nautical miles and above 500 nautical miles because of excessive atmospheric drag and excessive sensor modifications, respectively. Another constraint was, given a TM swath width of 100 nm, to maintain approximately 3 percent sidelap coverage at the equator. The resulting candidate orbit which meets these conditions is a 590 km altitude orbit with a repeat cycle of 15 days. Therefore, the overall timeliness value used in TOSS is 12.5 days.

#### 4.4 SYSTEM DESIGN TRADES

One of the most noteworthy features of the TOSS study is its success in bridging systems analysis and systems economics into a coherent total system evaluation tool. This is the first time that a careful and detailed analysis of a systems total expected performance was coupled with an equally powerful analysis of the system's expected economic benefits. Design of the TOSS system involves several major engineering trade-offs. Three of these trades were investigated on a basis of economics and end-to-end system performance in order to illustrate the use of TOSS as a design evaluation tool.

##### 4.4.1 NUMBER OF SPACECRAFT AND SENSORS

The first key system trade to be discussed involved the number of spacecraft in the system and the number of sensors per spacecraft. The critical trade parameters are timeliness, accuracy, and economic benefits - each of which is affected by the number of spacecraft. Economic loss can easily be expressed directly in the

U.S. Crop Survey benefits model as a function of accuracy and timeliness. The tradeoff discussed here is illustrated in Figure 4-6.

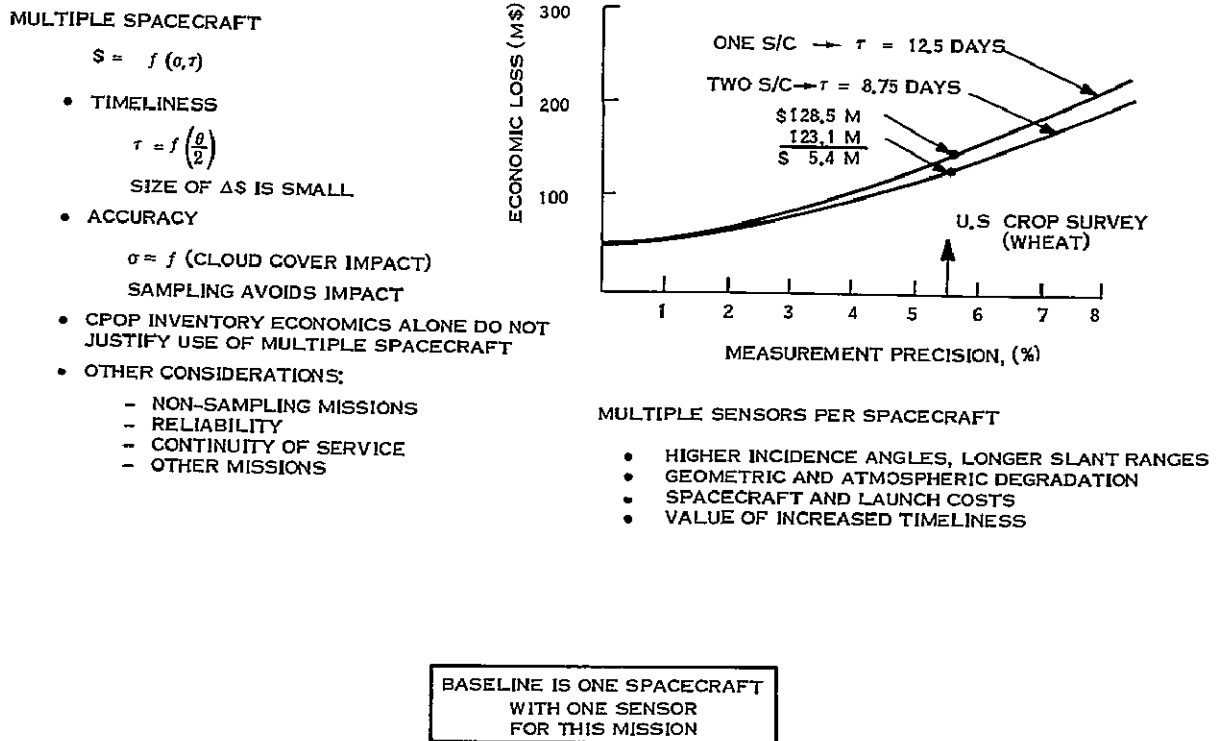


Figure 4-6. Number of Spacecraft and Sensors

The timeliness can be improved directly by increasing the number of spacecraft because multiple equally spaced satellites will reduce the effective repeat cycle,  $\theta$ . If one satellite has a 15 day repeat cycle then two similar satellites placed 180 degrees apart would have an effective repeat cycle of 7.5 days.

Multiple spacecraft can contribute to an accuracy improvement by either ensuring that an adequate number of samples are obtained cloud free by increasing the number of passes (observation attempts) over the area of interest. Or alternatively, multiple spacecraft can obtain even more samples (at the same confidence level) and improve the accuracy by decreasing the sampling error. For the TOSS baseline, the number of samples in the U.S. was already large enough to drive the sampling error contribution down. The key mechanism then, for the U.S., is that multiple spacecraft would assist in achieving the desired number of samples in spite of cloud cover.

The specific tradeoff made was between one and two spacecraft for a U.S. Wheat Crop Survey mission using ECON's U.S. benefits model. For this particular mission the TOSS sampling strategy of using floating

samples can avoid the effect of cloud cover impact by taking a population large enough to allow for those samples obscured by clouds. In the U.S., the initial number of potential sites was taken to be the 17,000 SRS sample sites because of their easily obtainable ground truth. Referring to the cloud cover curves in Section 3.4 these 17,000 sites are expected to yield over 8,000 cloud free samples. Thus, for the U.S., the accuracy is adequate for one satellite without having to increase the number of spacecraft.

As explained previously, 15 days is the baseline repeat cycle for a one-spacecraft system; adding another spacecraft reduces the repeat cycle to 7.5 days. The total time lag (timeliness) for a one-spacecraft system is 12.5 days as opposed to 8.75 days for a two spacecraft system. A difference in timeliness of 3.75 days produces an economic benefit differential of only 5.4 million dollars per year, as illustrated in Figure 4-6. (For illustration purposes, an MSS accuracy of 5.6 percent was used. Note that this is more than twice the expected TM accuracy of 2.2 percent for the U.S. wheat survey mission.) Since the addition of a second spacecraft accrues less than \$6 million in additional economic benefits, the U.S. Wheat Inventory mission alone does not justify the cost of a multiple spacecraft system.

A significant point regarding the preceding discussion is that it is based on a one sigma confidence level. That is, the indicated performance can be expected to be met for about six out of ten years. This is an unrealistically low confidence level to place on an operational system of such importance to the United States. More reasonable confidence levels for an operational system might be two or three sigma. These higher confidence levels would significantly change the preceding analytical assumptions and would quite readily change the conclusion to be that multiple spacecraft are required, even for the U.S. mission alone.

Additional factors which tend to tip the conclusion towards multiple spacecraft are that this is only the U.S. Wheat Inventory mission, other mission and other countries are much more sensitive to cloud cover and to timeliness. Similar trades were not made for other missions. It is probable that other-mission economics might justify a multiple spacecraft system. Some of those missions would have particular coverage requirements and the cloud cover problem could no longer be avoided by sampling strategy. Other considerations such as reliability and continuity of service would also affect the number of spacecraft required for other missions.

Further, the classifier approach assumed for this analysis is one that did not require the use of spatially registered multitemporal data. If the use of multitemporal techniques should be required or be found to provide significant performance improvements, then the use of the "floating sample" concept would no longer be appropriate and multiple spacecraft would be required. For all of the above reasons it is the conclusion of TOSS that additional analysis is required here; and that in all probability, multiple spacecraft systems will be necessary.

The use of multiple sensors per spacecraft is similar to the multiple spacecraft trade in that faster effective repeat cycle can be obtained; however, additional problems are introduced which must be considered. Problems such as atmospheric and geometric degradation, higher incidence angles, and longer slant ranges, in addition to increased system costs, must be weighted against the value of increased timeliness made possible by use of multiple spacecraft. Since the problems mentioned above present additional difficulties to the processing of crop survey data, one sensor per spacecraft was preferred for the baseline. Additional effort in this area is both warranted and desirable in the future.

#### 4.4.2 DOMSAT VS. TAPE COURIER

Two alternative methods were considered for transferring the remotely sensed data from the TDRS ground station at White Sands to the preprocessing facility (in the Washington area). One approach is to use a commercial Domsat link at the lower buffered data rate while the other approach was to place the data (in digital tape form) with a regularly scheduled air freight service. The key tradeoff parameters involved are implementation cost versus economic benefits (due to increased timeliness). This tradeoff was performed for a U.S. Wheat Crop survey mission only. The data volume was estimated to be approximately  $10^{11}$  bits per day, or less than 2 HDT's per day. Thus, the data volume posed no significant problems to either approach: Domsat or tape courier. The time lag of the Domsat approach is about 0.5 days compared to a tape courier via air freight lag of about 2 days (an increase of 1.5 days). These time lags contribute to a total system time lag of 12.5 days for Domsat and 14.0 days for tape courier. Using these values in the ECON US Wheat benefits model results in an economic benefit of \$415,000 per year if Domsat is used. That is, the 1.5 day faster Domsat provides an incremental benefit of \$415 K per year. Figure 4-7 illustrates this trade; note that the benefits are computed for an accuracy level of 2.11 percent corresponding to the Thematic Mapper in the U.S.

The cost of using the Domsat as the relay was computed by adding the cost of the 50 Mbs link (\$1.2 M per year) to the cost of leasing complete ground terminal facilities (\$2.1 M per year) which works out to slightly over \$350 per hour. The utilization of Domsat for the US Wheat Survey mission's data volume computes out to be \$110,000 per year. If the Domsat were used to handle the global wheat survey data volume ( $10^{12}$  bits per day), the cost would be \$740,000 per year. Tape Courier cost is about \$25 per tape per day. This includes shipping and handling. Annual U.S. and world missions implementation costs are then \$18,000 and \$260,000, respectively.

The tradeoff between implementation costs of Domsat and tape courier for the U.S. wheat mission results in a difference of \$92,000 per year. Since the incremental benefits of Domsat are \$415,000 per year, the total net economic benefits amount to \$323,000 per year in favor of Domsat. Therefore, the Domsat relay is cost effective and is included in the TOSS baseline system design.

#### TRADE PARAMETERS

- OPERATIONS \$
- TIMELINESS (\$ BENEFIT)

#### ASSUMPTIONS

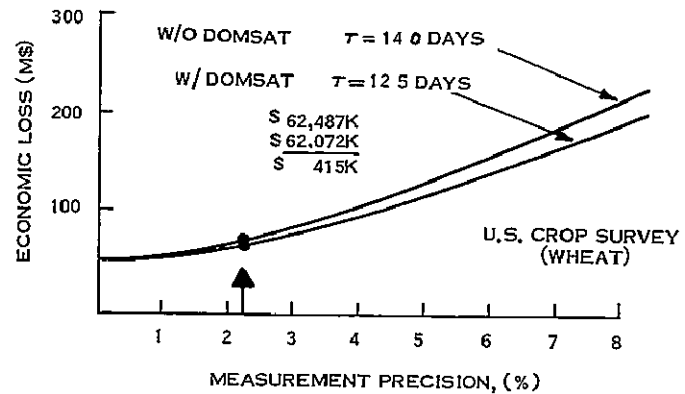
- U.S. WHEAT ONLY
- DATA VOLUME
  - $\sim 10^{11}$  BITS DAY
  - $< 2$  HDT/DAY
- TIME DELAY
  - DOMSAT  $\sim 0.5$  DAYS
  - AIR FREIGHT  $\sim 2$  DAYS
- OPERATION COST
  - CHANNEL COST  $\sim$  \$350 PER HOUR (TERMINAL AND 50 MBIT LINK)
  - COURIER COST  $\sim$  \$25 PER DAY PER TAPE (SHIPPING AND HANDLING)

#### TRADE RESULTS

- YEARLY U.S. WHEAT IMPLEMENTATION COSTS
  - DOMSAT - \$110 K
  - COURIER - \$18 K
  - $\Delta = \$92$  K
- YEARLY WORLD IMPLEMENTATION COSTS
  - DOMSAT - \$740 K
  - COURIER - \$260 K
  - $\Delta = \$480$  K

#### TRADE RESULTS (CONTINUED)

- YEARLY U.S. WHEAT BENEFIT
  - DOMSAT - \$62,072K
  - COURIER - \$62,487K
  - $\Delta = \$415$  K



#### DOMSAT IS COST EFFECTIVE

- U.S. WHEAT SAVINGS - \$332K
- GREATER SAVINGS EXPECTED FOR OTHER U.S. AND GLOBAL MISSIONS

Figure 4-7. Domsat vs Tape Courier

Since the above benefits were computed for the U.S. wheat survey mission only, it is expected that other missions, particularly a global crop survey mission, will return even greater benefits for using Domsat instead of a tape courier.

#### 4.4.3 UTILIZATION OF ON-BOARD RECORDER

The third system level tradeoff investigated with TOSS was the utilization of an on-board tape recorder as part of the spacecraft design. One of the basic ground rules provided at the start of TOSS was that the system would have available for its use the facilities of a TDRS (Tracking and Data Relay Satellite). However, the current concept for TDRS of two geosynchronous satellites with a ground station in White Sands, New Mexico will not provide total global coverage at all altitudes. There is a region centered over India called the Zone of Exclusion within which continuous spacecraft coverage will not be possible. The exact size of this zone is a direct function of the spacecraft altitude and is shown in general in Figure 4-8; for a more detailed treatment of this subject, the interested reader is referred to Appendix O. The extent of the wheat growing region within India is indicated by the dark shading on the figure. Given the use of TDRS, the question becomes: Is the cost of the alternative coverage for India (i.e., on-board recorder), worth the economic advantage of including India in a global wheat survey?

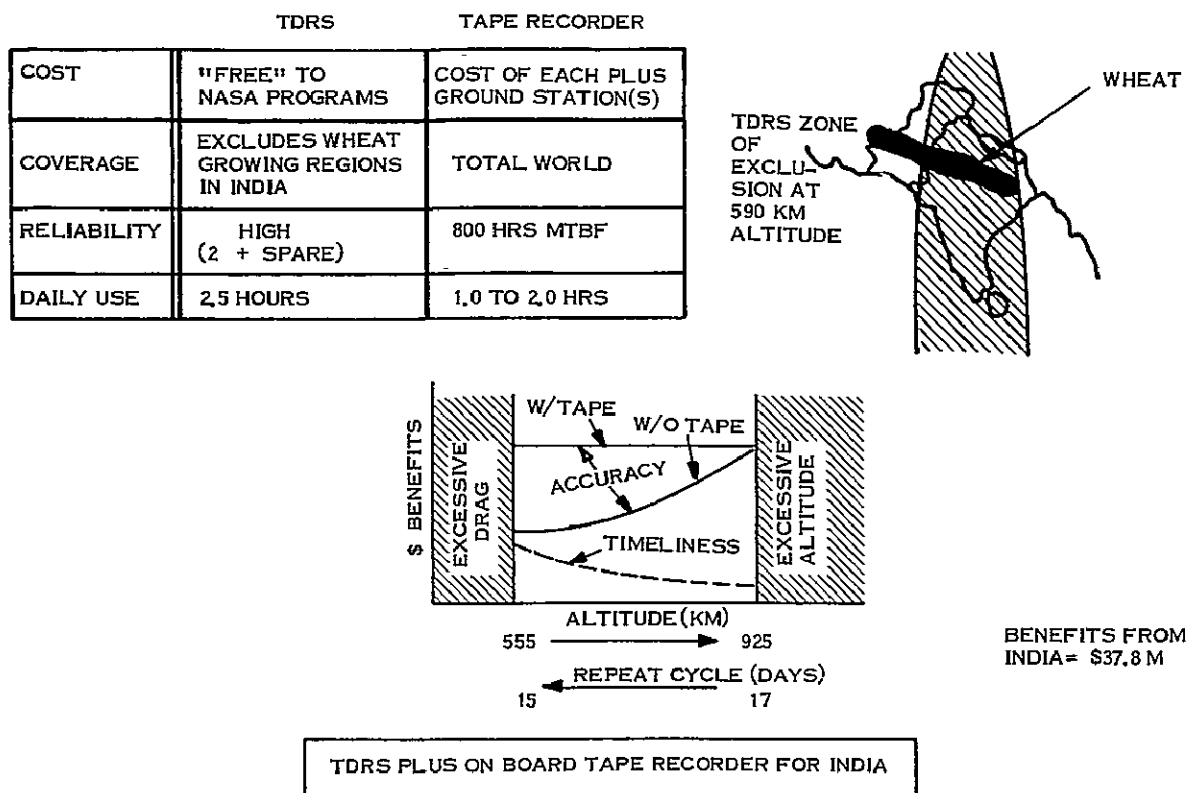


Figure 4-8. Communication Links: TDRSS vs On-board Recorder

The Global Crop Survey economic model was exercised for two cases to assess the benefits (to the U.S.) of including India in a global wheat survey. The model was run once with India and once without, all other conditions being the same. The direct benefits to the U.S. for Indian coverage are thus estimated to be \$ 37.8 million per year. This is a significant annual "loss" if provision is not made to include India in the coverage. A different way of interpreting this increment is that up to that amount could be spent in order to include India and the net results would still be beneficial.

There are several alternatives available to the system for providing continuous coverage of India. These include: use of on-board recorders, use of a ground station located in India, and even use of a tracking ship stationed in the Indian Ocean. The tradeoff of using an on-board tape recorder or not is illustrated in Figure 4-8. On this figure is shown the variation in benefits due to accuracy and timeliness as a function of spacecraft altitude. The contribution to benefits due to timeliness decreases as the spacecraft altitude increases since at higher altitudes the repeat cycle is longer and thus the data is on the average older for complete coverage. Accuracy can be considered as a function of altitude in that at higher altitudes the TDRS zone of exclusion is smaller and thus, the coverage of India's wheat region is greater. With a tape recorder to provide coverage through the zone of exclusion, the accuracy is no longer dependent on spacecraft altitude.

The result of this tradeoff investigation is the inclusion of an on-board recorder in the baseline design in addition to the use of TDRS. Further, the spacecraft altitude should be as low as possible, consistent with atmospheric drag considerations, in order to shorten the coverage repeat cycle.

## SECTION 5

### ECONOMIC ANALYSIS

The TOSS study represents a unique combination of economics and systems analysis applied to the Earth Resources Program. In particular, TOSS studied the design of an operational remote sensing satellite system which would capture certain economic benefits identified for a high priority earth resources application. The economic aspects of TOSS were performed by ECON Incorporated as part of the TOSS study team, under subcontract to General Electric.

This report section describes the econometric models used in TOSS and the economic analysis done as part of TOSS.

During the summer of 1974, ECON performed an overview study of the potential benefits that would likely be due to implementation of an ERS satellite system based on low altitude satellites of the LANDSAT type. This study classified benefits into eight generic categories spanning the range of earth resources. These categories include:

1. Intensive use of living resources - agriculture
2. Extensive use of living resources - forest, rangeland and wildlife
3. Inland water
4. Land use
5. Nonreplenishable natural resources
6. Atmosphere
7. Oceans
8. Industry

In addition to a review of the literature and current studies dealing with potential benefits of remote sensing earth resources, ECON performed three in-depth case studies and one ad hoc case study also in support of the overview effort.

The results of the above studies indicated firstly that satellites could become a cost-effective component of an ERS system with respect to surveys to U.S. territories alone and, secondly, that substantial benefits could result from the application of ERS data of a quality that could be provided by satellites applied to agricultural crop measurements, forest and rangeland management and inland water impoundment management.



There evolved from the analysis performed, only a limited number of benefit areas that are large enough to be permitted to drive the configuration of a satellite system and for which reasonable system configurations would capture a major portion of the total potential benefit. These areas appeared to include agricultural crop surveys, forest and rangeland management, water impoundment systems management and land use surveys.

Four case studies were selected by NASA for detailed analysis by ECON (1975) of economic benefits as a function of the performance parameters of an earth resources survey (ERS) satellite system. These studies include two case studies in agriculture, one addressing domestic temporal distribution of wheat, small grains (as a set) and soybeans and the second dealing with international trade in wheat, one study in rangeland management and one study in inland water impoundment management for hydropower and irrigation.

The subset of four studies cited above was chosen for in-depth analysis during 1975. In each of these in-depth case studies, ECON has determined the economic benefit of ERS activities as a function of three basic information system parameters, the measurement accuracy, the measurement frequency and the data availability lag (the time between when the measurement is made and when management information is available to decision makers.) The specific attributes of these particular four benefit areas which make them important to consider in the configuration of a satellite system are as follows:

1. Domestic temporal distribution of agricultural crops: wheat, small grains and soybeans - This mission was chosen because it is the most promising application of Landsat-type data obtained only over the U.S. The benefit is very large and preliminary Landsat investigations have demonstrated a technical capability for this mission. This mission requires wide-area crop monitoring throughout the growing season to reduce sampling errors present in measurements of growing crop acreage such that, over the U.S. alone, a Landsat type of satellite system is cost-effective compared to alternative data collection methods.
2. International trade of agricultural crops: wheat - This mission was chosen because of the considerable political and economic significance of international trade in wheat. There appears to be a very significant economic benefit possible from improved worldwide measurements of crop production, not only for the U.S. but for nearly all other nations as well, and a satellite system appears to offer the only technical solution to performing this mission. It is conceivable that this mission could result in a very significant, yet modestly low cost, foreign aid program for many nations. The sensing requirements for this mission are more or less similar to those of domestic crop surveys except for the grossly increased area for which coverage must be provided and due to the fact that, for many areas, reliable ground truth data are unavailable.
3. Rangeland management - The rangeland management mission was chosen for several reasons. First, although the benefits are much less than for the agricultural missions, the potential benefits in the area of rangeland management are nonetheless quite significant. Second, the remote sensing requirements for this mission are quite different from the agriculture missions. Rangeland management stresses timeliness, both in the form of measurement frequency and in the form of data availability lag. Third, rangeland management is a highly dynamic process that stands to be significantly improved by improved management information. Fourth, the geographical areas of importance in rangeland management are of importance in the domestic crop measurement mission. Fifth, a substantial technical capability has already been demonstrated by Landsat-1 investigations. Lastly, this application also holds a substantial promise of benefit for many foreign nations.

4. Inland water impoundment management for hydropower generation and irrigation - This mission was chosen because it lies totally outside the area of living resources, because it requires close monitoring of specific areas, especially during the winter months when most living resources are idle, and because the anticipated benefits are substantial. The major function for remote sensing in this mission is to map winter snow cover, a capability that has been aptly verified by Landsat-1 investigations. The water impoundment management mission poses one difficulty not experienced in the other missions studied. That is that the water system characteristics, the management policies and constraints, and the management information availability are unique for each water impoundment system. Thus, each system must be studied separately and the potential benefits attributable to remote sensing can be quite different for geographically similar systems.

In summary, each of the four missions were chosen because they are economically and politically significant, because they are complementary in their area coverage requirements, and because appropriate technical capabilities have either been demonstrated or at least indicated.

The economic effort reported in this volume represents the application of ECON's economic benefits analysis of an operational earth resources satellite system with special emphasis on agricultural crop surveys. The methodology, data and approaches for this study have been mostly developed under contract NASW-2558 for NASA's Office of Applications (1975) and are fully documented in the following reports:

- (1) The Value of Domestic Production Information in Consumption Rate Determination for Wheat, Soybeans and Small Grains, by John Andres, ECON Report No. 75-127-3, August 31, 1975
- (2) The Value of Forage Measurement Information on Rangeland Management, by Keith Lietzke, ECON Report No. 75-127-4, August 30, 1975.
- (3) A Parametric Study of the Value of Hydrological Information for Irrigation and Hydropower Management of the Feather River, by Elliot Wetzler, ECON Report No. 75-127-5, August 30, 1975.
- (4) U.S. Benefits of Improved Worldwide Wheat Crop Information from a Landsat at System, by Andrew Seidel, ECON Reports No. 75-122-1A, B, C, D, August 31, 1975
- (5) A Preliminary Study of the Statistical Analyses and Sampling Strategies Associated with the Integration of Remote Sensing Capabilities into the Current Agricultural Crop Forecasting System, by Francis Sand and Robert Christie, ECON Report No. 75-127-1, June 30, 1975.

In addition to these 1975 reports, reference has also been made to ECON's 1974 "ERTS Overview" study:

- (6) The Economic Value of Remote Sensing by Satellite: An ERTS Overview and the Value of Continuity of Service, ECON Reports No. 74-2002-10 (13 Volumes), December 20, 1974.

Because these econometric models and the previous ECON economic work has been fully and completely documented, this TOSS final report will not duplicate that material. Rather, the following sections will present a summary of this effort as it applies specifically to TOSS and will describe the new economic work performed as part of TOSS.

Because these econometric models and the previous ECON economic work has been fully and completely documented, this TOSS final report will not duplicate that material. Rather, the following sections will present a summary of this effort as it applies specifically to TOSS and will describe the new economic work performed as part of TOSS.

During the early part of the TOSS effort, the study team was directed to concentrate fully on the two agricultural applications and to wrap up the activity on the other two applications (Rangeland and Water). Therefore, the economic activity and econometric models related to agriculture only will be presented in this report. The reader interested in the economics of the other two applications is referred to the above referenced ECON Inc. reports.

### 5.1 VALUE OF AGRICULTURAL INFORMATION

Information on crop harvests is important to several groups within the United States economy. Farmers consider past and projected harvests in deciding how to use their productive land. Food processors and other consumers use crop harvest information in planning their purchases and inventories. Various agents participate in the spot and futures markets for agricultural commodities. All use crop harvest information to help them anticipate the prices at which they buy and sell.

In a market economy, such as the United States, information is transmitted not only through production reports such as those published by the USDA, but also through the prices themselves. Thus, an agent who makes his decisions based on prices alone is still responding to the particular information, or misinformation, that is current in the economy.

Economic value of crop harvest information can be realized by any of the various agents whose decisions are made in response to this information. It is convenient to classify these agents according to their decision making functions: production, consumption, and distribution. Of course, a single individual or company may function in more than one of these ways. For example, a farmer is ordinarily involved in production, but whenever he sells his crops, he is involved in distribution. More significantly for this study, he is also involved in distribution if he stores some of the crop for later sale.

It is easy to see that crop harvest information may have a direct value in leading to appropriate levels of production and consumption. These kinds of value are not the subject of this study however, which concentrates on the value of improved information for the distribution of the crops produced. More specifically, this study concerns distribution from one time period to another, and not necessarily from one consumer to another. This temporal distribution is particularly important for grain crops, which are easily storable, but which can be produced only during part of the year, and for which there is a substantial demand throughout the entire year.

Obviously, consumers benefit if the rate of consumption of a grain crop can be made approximately constant throughout the year, rather than being large when the harvest rate is large and vanishing when the harvest season is over. In a market economy, the advantage of one consumption pattern over another is reflected in precise quantitative terms by the price fluctuations. When prices are high, each unit of consumption is more highly valued than when they are low. Not surprisingly, higher prices usually go with lower consumption rates.

This relationship can be captured in the demand function for the crop in question. Further, the demand function makes possible the calculation of the total value to the consumers associated with any pattern of consuming a given total crop throughout the year. It turns out that the most valuable consumption pattern is characterized by constant prices (except for a small correction due to the costs associated with storage.)

There are, thus, two equivalent viewpoints on the potential value of improved crop harvest information. According to one viewpoint, accurate knowledge of the total annual production should permit storage of the appropriate fraction of the harvest in order to smooth out undesirable fluctuations in the consumption rate. According to the second viewpoint, the knowledge results in the smoothing out of fluctuations in the price of the grain. This second viewpoint suggests the natural mechanism by which the information is used in a market economy -- namely, to predict prices. If information on the coming harvest indicates that it is to be smaller than usual, speculators will be led to expect higher than usual prices at harvest time and, motivated by potential profit, they will store larger amounts of the current supply. The cumulative effect of these actions is to raise the current price and to lower the price at harvest time, thus limiting the price fluctuation.

If perfect information were always available, we would expect constant prices throughout the year (except for the correction due to the costs associated with storage). However, significant uncertainty about grain supply is probably a permanent feature of our world, so that some price fluctuations are inevitable. Any improvement in knowledge of the annual harvest will have a value as long as it is available in time to affect storage versus consumption decisions regarding some part of that harvest.

Dozens of research experiments have clearly demonstrated the ability of remotely sensed data to provide accurate estimates of currently growing acreage of the wheat crop. Of particular interest is the ability of remote sensors on satellites (such as Landsat) to provide these measurements. Although it may turn out that useful measurements of crop condition are also possible, it is assumed for this study that the objective of the remote measurements is to determine growing acreage. As indicated above, acreage information has value for improved (storage versus consumption) decision making only to the extent that it leads to information on the total annual production. Therefore, the following paragraphs will now consider the links in the chain connecting these two kinds of information.

Historical data are readily available connecting growing acreage at a given time of year with the eventual production. Thus, an acreage estimate provides an essential component of an estimate of potential production. It is understood that the actual production to occur in the future may differ from the potential production of a given time because of various unpredictable events. For example, the potential production just after planting represents the best estimate that could be made of the final production if one knew exactly how many acres were planted. The actual production will differ from this potential production though, if some of the crop is destroyed, if weather is atypical, or if some farmers find reason to abandon or plow the crop under rather than harvest it. The potential production itself changes with time, approaching the actual production by a random path. By the end of the crop year, the potential production is no longer varying and equals the actual production.

The concept of measurement error applies to an estimate of the growing crop acreage (and thus to an estimate of the potential production) at measurement time. The forecast error, on the other hand, is composed of two parts -- the error in measurement of potential production and the actual production. Both of these are influenced strongly, however, by the properties of the information system. The first component is directly related to the precision of the measurement system leading to acreage estimates. The second component, the difference between potential and actual production, is directly related to the availability lag (time interval) between measurement and dissemination of the processed results. The total error in the forecast consists of the measurement error plus x days worth of the kind of random errors that account for the need for information in the first place.

Summarizing, the most important descriptions of a remote sensing system's performance in producing crop harvest information are its precision in measuring acreage and its availability lag in releasing such information. In addition, the publication frequency of such information is important in estimating the economic benefits.

Consumption rates are determined by those who hold inventories. Whether his primary business is production, processing, transportation, storage, or speculation: to the extent an agent holds inventories, he is contributing to the transformation of the uneven harvest pattern into the smoother consumption pattern. Inventory holders are motivated to make their transactions profitable and, thus, to become the recipients of the benefit associated with the improved consumption pattern. But, because of competition, the benefits tend to be passed on by stages to the ultimate consumers who purchase either grain products such as bread, or meat from livestock raised on the grain.

Inventory holders make their buying and selling decisions based on prices and price expectations. Because of the action of hedgers and speculators in the futures market, any relevant information in the hands of any of these agents is quickly reflected in the set of market prices. In particular, the publication of a

report containing valuable crop harvest information is enough to ensure the realization of that value through prompt adjustment of spot and future prices.

## 5.2 OVERVIEW OF U.S. CROP SURVEY MODEL

During 1975 ECON conducted a detailed case study and developed an econometric model to quantify the value of improved crop harvest information of U.S. crops to the U.S. economy. This section will briefly summarize ECON's modeling effort and describe the input parameters used in the U.S. Crop Survey model. The reader interested in further detail regarding this model is referred to Appendix A and beyond that, to the original complete ECON documentation.\*

Information about the current state of the growing crops in the U.S. is used to formulate crop production forecasts, which, in turn, are used by inventory holders to decide upon the rate of inventory depletion which maximizes their profit. Given competitive economic conditions, it can be shown that this profit-maximization behavior on the part of inventory-holders is also optimal from the point of view of consumers in the aggregate. The subject of this model, then, is the effect of improved information about current crop status upon consumer welfare and, in particular, the type of information analyzed is the measurement of currently growing crops, by crop type.

An extension of ECON's 1974 model for distribution benefits of improved crop production information has been developed. The 1974 model, developed by Bradford and Kelejian, determines the change in wheat inventory holding patterns that can be expected from more accurate measurements of the growing crop. Further, it translates this change into monetary benefits by the use of an empirically derived demand function for wheat. The present extension permits efficient computation of economic loss due to measurement errors in the information system as well as the economic loss due to the specified data availability lag, and the economic loss due to the time period between successive report publications.

The economic loss due to inefficient temporal distribution of a year's grain crop is a simple function of the variability of the published monthly total production estimates and the slope of the demand function. The equation is

$$L = k \sum_{n=1}^{m+1} E_n \sigma_{n-2}^2 \quad (1-1)$$

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\*Andrews, John, "The Value of Domestic Production Information in Consumption Rate Determination for Wheat, Soybeans, and Small Grains," ECON, Inc. Report No. 75-127-3. 31 August 1975

where:

m = the number of decision periods in one year (assumed in the study to equal 12)  
k = minus one-half times the slope of the demand function with price based on monthly consumption quantities

$$E_n = \frac{r}{(1+r)^m - (1-r)^{n-1}}, \quad n = 1, \dots, m$$

$$\frac{1}{(1+r)^m - 1}, \quad n = m + 1$$

with r as the discount rate

$\sigma_j^2$  = the period (monthly) production forecast variances;  $\sigma_{-1}^2$  is the variance of the annual production estimate published at the beginning of the crop year, and  $\sigma_j^2$  (for j20) is the variance at the beginning of the j + 1 month of the next published monthly estimate.

Equation (1-1), the major result of this ECON study, gives the economic loss to the United States associated with a specified sequence of crop harvest information variances  $\sigma_{-1}^2, \sigma_0^2, \dots, \sigma_{11}^2$ .

For this study, it was assumed that forecasts would be published monthly (M = 12) and that the appropriate discount rate is r = .005 (corresponds to an annual discount rate of 6.2%). For these values, the coefficients  $E_n$  are given as shown in Table 5-1.

Table 5-1. Coefficients of Forecast Variances in Loss Function at Annual Discount Rate of 6.2%

Crop Month n	$E_{n+2}$	Crop Month n	$E_{n+2}$
	(Coefficient of $\sigma_n^2$ ).		(Coefficient of $\sigma_n^2$ ).
-1	.0811	5	.1597
0	.0882	6	.1912
1	.0968	7	.2384
2	.1073	8	.3171
3	.1204	9	.4745
4	.1373	10, 11	.9466

By "economic loss" is meant the average total loss due to uncertainty in the annual production. Thus, to reduce it to zero, one would have to be able to predict perfectly as well as to measure perfectly. In addition to perfect measurement one would need to perfectly address other factors such as weather and its consequences, insect damage, or changes in harvest plans.

Note that equation 1-1 expresses the net economic loss as a function of the production estimate variance not the variance of potential production, the measurable parameter. The basic relationship must be reexpressed in terms of a measurement precision parameter and a total availability lag parameter indicative of a remote sensing system in order to be applicable for the purposes of this study. To apply equation (1-1) to a particular agricultural crop and information system, we must find expressions for  $\sigma_{-1}^2, \dots, \sigma_{11}^2$ . For an information system in operation or extensive experimentation, of course, these quantities can be estimated from its actual output. For example, the economic loss associated with the current USDA crop reporting system can be determined from records of its monthly production reports (refer to Appendix B). For a new or proposed information system the values of  $\sigma_{-1}^2, \dots, \sigma_{11}^2$  must be estimated based on projected system performance.

The quantities  $\sigma_j^2$  required in the loss function calculated in equation 1-1 are variances of production forecasts. For  $j = 0, 1, \dots, 11$ ,  $\sigma_j^2$  is the variance of the forecast to be obtained one month later, conditional on the forecast at time  $t_j$ . The term  $\sigma_{-1}^2$  is the variance of the first forecast, conditional on planted acreage only. To calculate  $\sigma_{-1}^2, \sigma_0^2, \dots, \sigma_{11}^2$  we assume that the forecasts are measurements of the potential production. Further, we assume the measurement made at a given time is unbiased and is independent of the growth process and of the measurement made at a different time.

The relationship between the growth process, the measurement process, and the sequence of forecasts is diagrammed in Figure 5-1. The growth process consists of a sequence  $\{P_j\}$  of values of the potential production differing by independently distributed random terms  $E_G(j)$  with zero means, and variances of  $\sigma_G^2(j)$ . A measurement of  $P_j$  produces a result  $P_j$  differing from  $P_j$  by the measurement error  $E_M(j)$ . The measurement error  $E_M(j)$  has a mean of 0 and a variance of  $\sigma_M^2(j)$ . The sequence of forecasts  $\{P_j\}$  has the difference term  $\phi_j$ , and it is the variance  $\sigma_j^2$  of  $\phi_j$  that enters the loss function of equation 1-1.

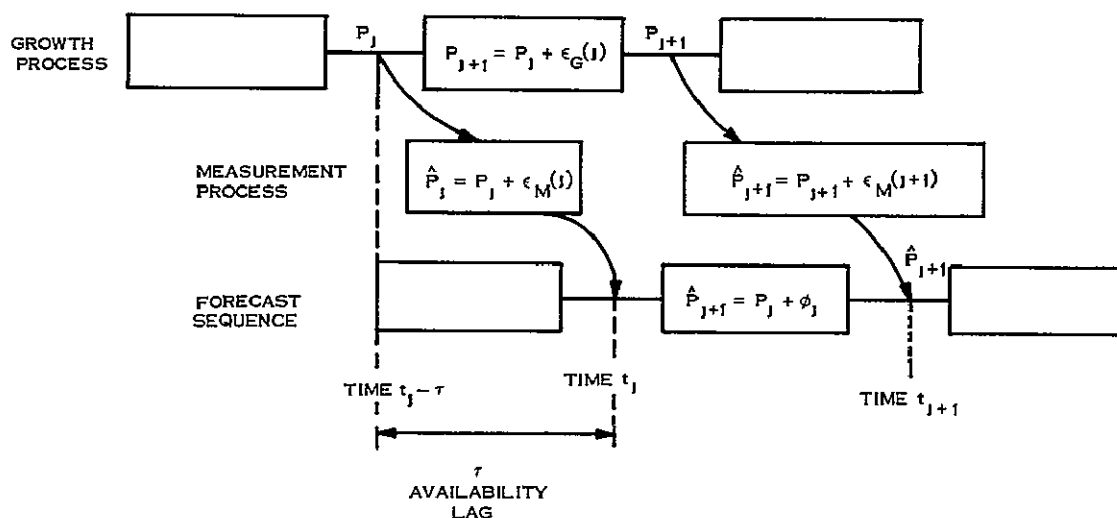


Figure 5-1. Overview of Harvest Information Process



For  $j = 0$ , we can write

$$\begin{aligned}\phi_j &= P_{j+1} - P_j = P_{j+1} + E_M(j+1) - P_j - E_M(j) \\ &= E_G(j) + E_M(j+1) - E_M(j)\end{aligned}$$

This implies that

$$\sigma_j^2 = \sigma_M^2(t_j - \tau) + \sigma_G^2(t_j - \tau) + \sigma_M^2(t_{j+1} - \tau) \quad (1-2)$$

Recall that  $\sigma_{-1}^2$  is the variance at the beginning of the crop year and can be shown to be given by:

$$\sigma_{-1}^2 = \sigma_M^2(t_0 - \tau) + A_p^2 \text{Var}_G \frac{\sum_{i=-m}^{-1} G^2(t_i - \tau)}{\sum_{i=-m}^m G^2(t_i)} \quad (1-3)$$

where:

$A_p$  = the planted acreage

$G(t)$  = the fraction of the growing crop which is still in the growth stage at time  $t$

$\text{Var}_G$  = total growth variance during the season from planting to harvest

Summarizing then we have equation 1-1 which expresses the economic loss as a function of the variance in the periodic production forecasts ( $\sigma_j^2$ ) and equations 1-2 and 1-3 which relate this forecast variance to a measurement error variance ( $\sigma_M^2$ ) and the growth variance. By using historical published data together with actual or estimated values for the measurement error it is now possible to compute the economic loss of a crop production information system as a function of its measurement accuracy.

To compute an economic loss for a specific system (either actual or projected) a series of measurement error variances  $\sigma_M^2(t)$  are computed for each period of the crop year for that system. Analysis of historical data will produce a series of growth variance terms for the corresponding periods. The measurement variances are then combined with the growth variances, period by period, to form the total production forecast variances. The series of production forecast variances are then entered directly into the economic loss equation to yield a specific dollar performance level.

If a simplifying assumption is made as to the variation of the measurement error during the crop season then it is possible to express the preceeding equations more simply. If the measurement error variance is assumed proportional to the actual acreage growing then the economic loss can be written as:

$$LOSS = A(\tau) + B(\tau) \epsilon^2$$

where  $\tau$  is the availability lag in days and  $\epsilon$  is ratio of  $\sigma_M$  to the mean at the point prior to harvest when the entire crop is growing. This assumption of proportionality corresponds to the fact that as harvest occurs there is less wheat to measure and the percentage error will increase. For wheat in the United States sample values of  $A(\tau)$  and  $B(\tau)$  are:

$\tau = 0$ days	$A = 24.5$	$B = 30,536$
$\tau = 10$ days	$A = 24.7$	$B = 35,383$

These values will produce losses in millions of 1975 dollars when used with the preceeding equation. Figure 5-2 shows the relationship between economic loss and measurement accuracy for this proportionality assumption.

A different, but equally simplifying assumption is that the measurement accuracy parameter,  $\epsilon$ , stays constant throughout the crop cycle and does not increase as harvest occurs. This is consistent with the concept that a remote sensing based system will be able to perform better as the season progresses (more temporal data and more distinctive signatures) and that this improvement will balance the above discussed decrease. For wheat in the United States sample values of  $A(\tau)$  and  $B(\tau)$  for this assumption are:

$\tau = 0$ days	$A = 48.9$	$B = 21,644$
$\tau = 10$ days	$A = 49.5$	$B = 25,463$
$\tau = 20$ days	$A = 50.1$	$B = 30,111$
$\tau = 30$ days	$A = 50.9$	$B = 35,588$

Again, these values will produce losses in millions of 1975 dollars. Figure 5-3 shows the relationship between economic loss and measurement accuracy for this assumption of constancy. It is this assumption and the losses of Figure 5-3 which were used throughout the TOSS study for the U.S. Crop Survey Model.

### 5.3 OVERVIEW OF GLOBAL WHEAT SURVEY MODEL

#### 5.3.1 INTRODUCTION

To date, worldwide crop measurements are heavy with errors and they are late, if available to all. Improved accuracy and timeliness of worldwide crop measurements may, on the average, improve the ability of famine-prone areas to prepare for harvest shortfalls months in advance of their current capabilities and eliminate,

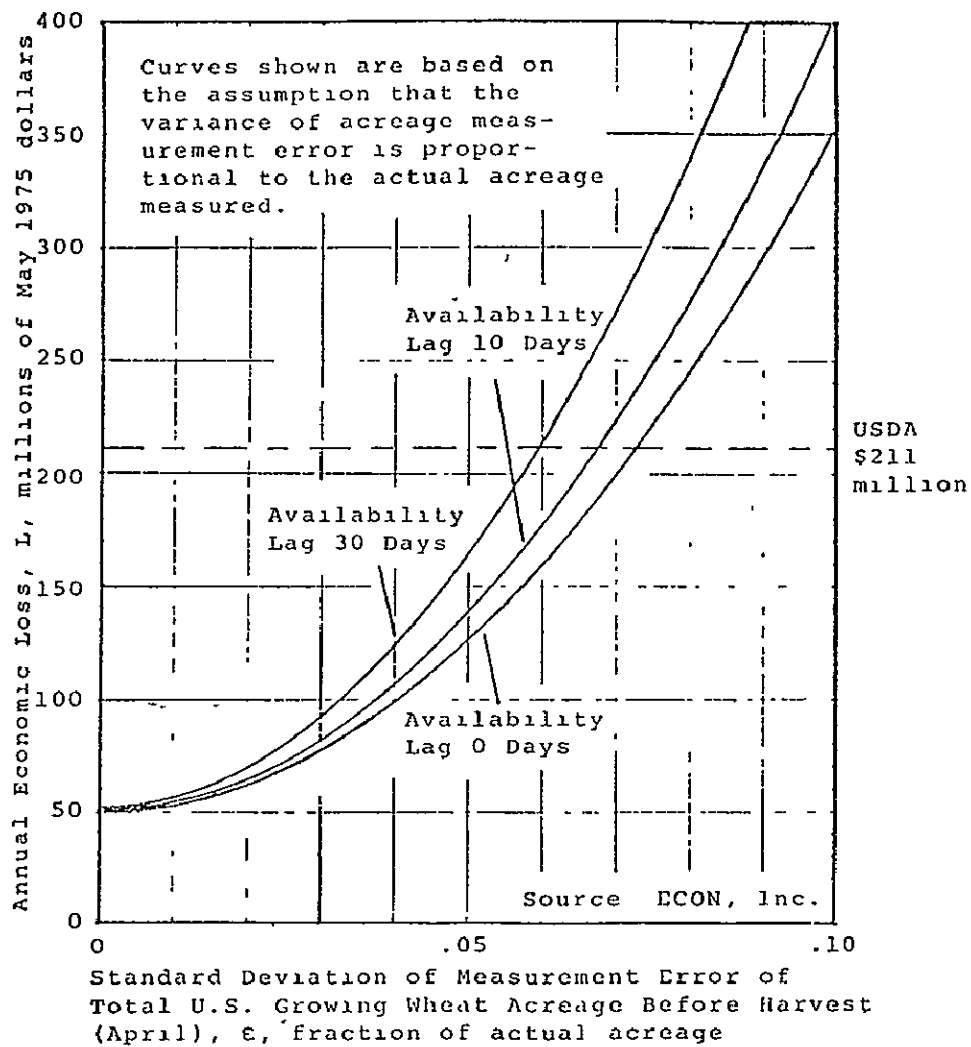


Figure 5-2. Annual Economic Loss Due to Imperfect Wheat Production Forecasts

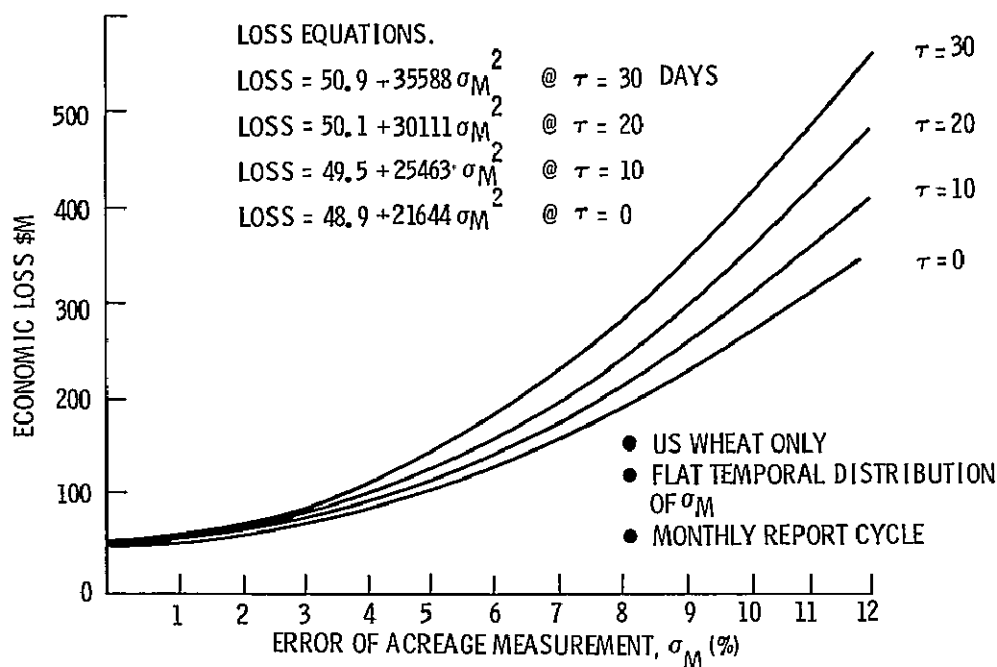


Figure 5-3. U.S. Wheat Survey Model for TOSS

or at least reduce the suffering that otherwise would have occurred. Similarly, improved worldwide crop monitoring would give all trading partners a clearer picture of the market and reduce the frequency and amount of waste owing to inaccurate information among the market participants. Short of involving the specter of starvation, improved crop information may lead to a closer worldwide agreement of spot prices, where any difference in spot prices between regions may be interpreted as an economic measure of existing inefficiencies in distribution of crops and relative scarcities.

How little is known about future supplies of commodities today is best reflected by the violent movement of wheat prices over the past several years. Movements in the price per bushel from \$2 to \$6, to \$4, to \$6, to \$3, all within a few dozen months, are but one very direct expression of this uncertainty and lack of information.

This study is an attempt to measure the economic value of the improvements in worldwide wheat crop information, promised by the use of remote sensing earth resources satellites. Because the costs of such an information gathering system are being borne by the United States, it is appropriate that the benefits be estimated with specific reference to the United States.

The potential value of improving information rests on two results in economic general equilibrium analysis. First, the allocation of resources to satisfy needs (market efficiency) improves with better public information, second, all parties engaged in rational, free trade stand to gain from such trade. These general statements suggest -- a priori -- that an improved, public, worldwide crop monitoring system may benefit at least some countries without hurting any others.

In addition to the basic assumption that all Landsat information will be made available to all countries simultaneously there are two other assumptions pervading this analysis; first, the world market place will use Landsat information only when and if that information is more accurate than the information from currently available alternative sources; second that world trade will be rational.

Although the Landsat system has the potential to monitor many crops worldwide, this study focuses on one of the most important -- wheat. To be sure, the benefits from improved crop information will be larger, the greater the crop coverage. Nevertheless, wheat is a major world crop and likely to account for a large share of the benefits from Landsat.

### 5.3.2 SUMMARY OF THE ECONOMETRIC MODEL

In order to estimate the economic benefit to the U.S. of a global wheat survey system ECON Inc. has developed an econometric model identified as AGR-ECON II. The overall logic of the model is presented in Figure 5-4, Flowchart of Wheat Market Model. Data were assembled over a period of many months from a variety of sources which are listed in Table 5-2. Econometric estimates of the equations of the model were obtained by regression techniques using statistical programs, designed for econometricians. The full description of the estimation results, which is too lengthy to describe here, is contained in Chapter 12 of Part III of ECON's report to NASA on the worldwide agricultural application.

A brief recapitulation of the model is as follows. As can be expected, the optimal price and flow depend on the demand and supply situations of various countries. Prior information regarding the various supply situations enters the system as "crop forecasts". Thus forecasts, in general, have error terms whose distributions depend on the state of the world's forecasting capabilities. Thus, the optimal price and flow, as well as the corresponding welfare pertaining to importing and exporting countries, are functionally related to the respective crop forecast capabilities of the various countries involved in world trade.

Since the price and flow of wheat, or any other commodity, are conditioned by the availability of other substitutes (e.g., corn, rye, oats, etc.), it is necessary to take into account the non-zero cross-elasticities of wheat with respect to the prices of its substitutes and complements. These factors are treated in the model as exogenous and appear in the various demand and supply equations. Further, transportation costs must be properly incorporated into the objective function.

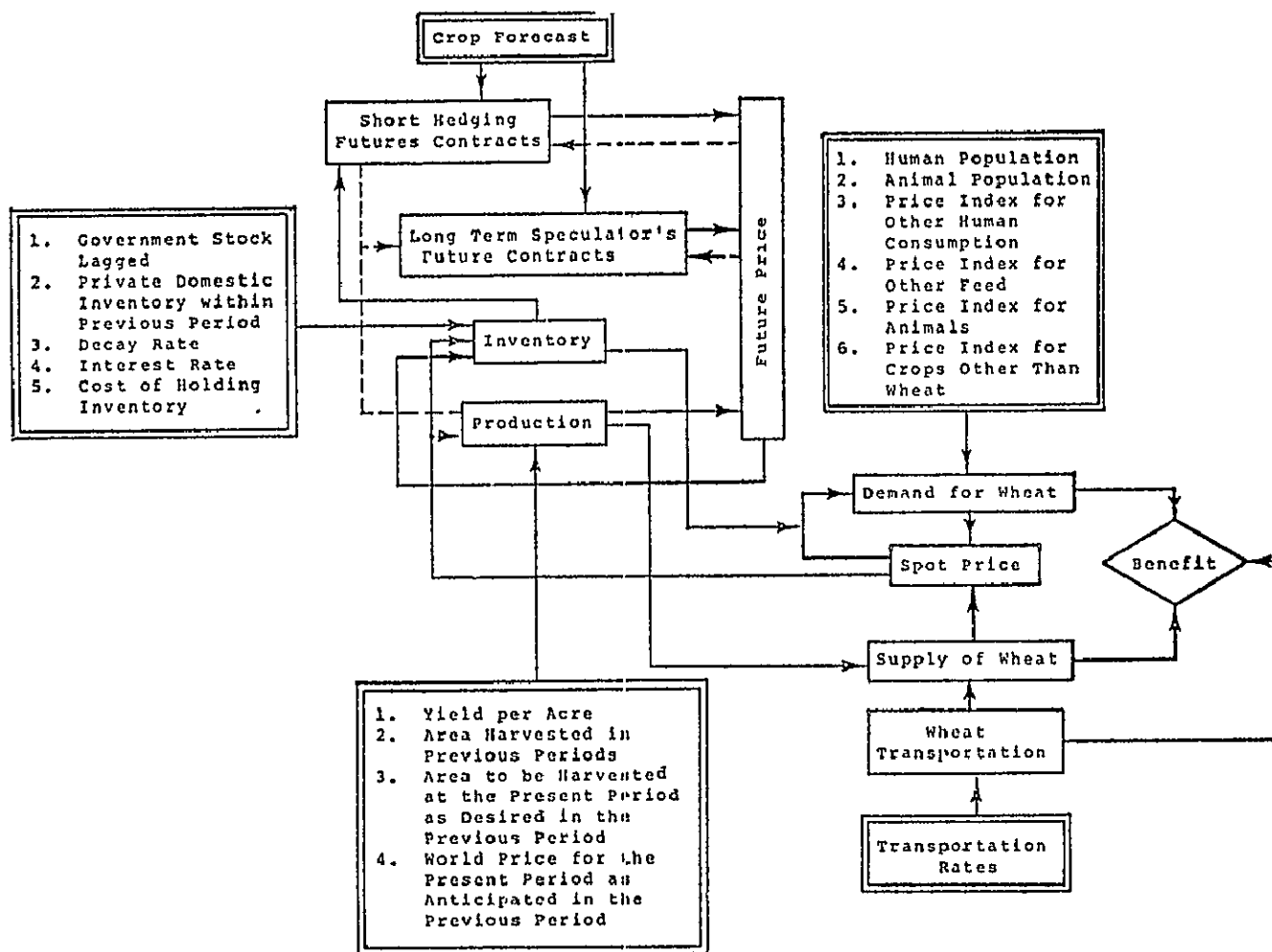


Figure 5-4. Flowchart of Wheat Market Model

Table 5-2. Sources of Data

FAO Production Yearbook  
FAO Trade Yearbook  
FAO Monthly Bulletin  
IWC World Wheat Statistics  
IWC Review of World Wheat Situation  
Grain Bulletin, Commonwealth Secretariat  
 Commodity Research Bureau Commodity Yearbook  
 Foreign Agriculture Service Foreign Agriculture Circular, FG 10-74 April 1974  
 USDA Food Grain Statistics various issues  
 IMF International Financial Statistics  
 FAS World Demand Prospects for Wheat in 1980 Report #62  
 UN Demographic Yearbook  
Chicago Board of Trade Statistical Supplement  
 FAS World Grain Trade Statistics

Owing to the nature of this study, "time" also is an important dimension in the model. This is essential for a number of reasons. First, wheat can be carried from one period to the next -- depending on the inventory holder's reaction to market anticipations. These anticipations can change from month to month and so can the inventory holders' positions. These changes, of course, influence welfare through price and consumption. Second, the benefits measured in this model, as in reality, depend heavily on the accuracy of market anticipations which, in turn, is a function of crop forecast accuracy. These accuracies change with the length of time to harvest and, therefore, the model distinguishes between gains and losses for different length forecasts.

The economic relationships of the specific model are summarized in Table 5-3 and 5-4, respectively. A semi-reduced form of these equations for the  $i^{th}$  countries' demand and supply curves are used in the actual benefits calculation so as to reduce the number of dimensions involved in the solution.

### 5.3.3 BENEFITS ESTIMATION

The estimation of long-run benefits to the U.S. is accomplished in the model following the logic of Figure 5-5. World demand on the open market for wheat is already known from ECON's previous econometric work and the historical supply by U.S. farms to the market is known and represented in ECON's worldwide wheat databank. The impact, on the supply side, of improved crop forecasting is treated as a long-term

Table 5-3. Definition of Variables

$n$ :	Number of countries
$j$ :	Superscript denoting country; $j:1, 2, \dots, J$
$t$ :	Subscript for time
$Q_t^{(j)}$ :	Production
$A_t^{(j)}$ :	Harvested acres
$Y_t^{(j)}$ :	Yield per acres
${}_t A_{t-\tau}^{(j)}$ :	Desired acres harvested for time $t$ as of time $t-\tau$
$P_t^{(j)}$ :	Spot price
${}_t P_{t+\tau}^P$ :	World price at time $t+\tau$ as anticipated in time $t$
$D_{*f,t}^{(j)}$ :	Desired stock of private domestic inventory
$D_{I,t}^{(j)}$ :	Actual stock of private domestic inventory
$G_{I,t}^{(j)}$ :	Government stock of domestic inventory
$I_t^{(j)}$ :	Total stock of inventory
$\delta$ :	Decay rate
$r$ :	Interest rate
$c^{(j)}$ :	Cost of holding a unit of inventory over a unit of time
$\Delta$ :	Difference operator, i.e., $\Delta X_t = X_t - X_{t-1}$ where $X$ can be any variable



Table 5-3. Definition of Variables (Cont.)

$C_t^{(j)}$	Demand for human consumption
$F_t^{(j)}$	Demand for feed
$E_t^{(j)}$	Demand for seed
$D_t^{(j)}$	Total demand
$Z_t^{(i,j)}$	Export from country i to country j
$T_t^{(i,j)}$	Transportation cost of unit commodity from country i to country j
$\overline{P}_{c,t}^{(j)}$	Price Index for other human consumptions
$\overline{P}_{F,t}^{(j)}$	Price Index for other feed
$P_{A,t}^{(j)}$	Price Index for animals (cattle, hog, sheep)
$\overline{P}_t^{(j)}$	Price Index for crop other than j
$\rho_{1,t}^{(j)}$	Human population
$\rho_{2,t}^{(j)}$	Population of animals demanding feed
$\tau^P_t$	Futures World Price for time t+T as of time t
$\tau^H_t$	Short hedging futures contracts for time t+T as of time t
$\tau^L_t$	Long speculation of demand for futures contracts for time t+T as of time t
$\tau^\sigma_t$	Standard deviation of world crop forecast error with lead time $\tau$
$\tau^Q_t^{(j)}$	Production at time t+T as expected at time t
$S_t$	Total supply

Table 5-4. Relationships Among Variables

$$Q_t^{(j)} = A_t^{(j)} \cdot Y_t^{(j)} \quad (1)$$

$$A_t^{(j)} = \alpha^{(j)} A_{t-h}^{(j)} + (1-\alpha^{(j)}) A_t^{(j)} \quad (2)$$

where  $\alpha$  is exogenous

$$h A_{t-h}^{(j)} = g_h^{(j)} P_{t-h} \quad (3)$$

where  $g^{(j)}$  is exogenous

$$\Delta Q_{*I}^{(j)} = q_I^{(j)} \left[ \left( \frac{1-\delta}{1+r} \right)^\tau \cdot \tau P_t^{(j)} - P_t^{(j)} - c_t^{(j)} \right] \quad (4)$$

where  $q_I^{(j)}$  and  $\tau$  are exogenous

$$\begin{aligned} \Delta Q_{*I}^{(j)} &= D_{*I}^{(j)} - D_{*I}^{(j)} = \gamma^{(j)} \left[ D_{*I}^{(j)} - D_{*I}^{(j)} \right] \\ D_{*I}^{(j)} &= \gamma^{(j)} q_I^{(j)} \left[ \left( \frac{1-\delta}{1+r} \right)^\tau \cdot \tau P_t^{(j)} - P_t^{(j)} - c_t^{(j)} \right] + (1-\gamma^{(j)}) D_{*I}^{(j)} \end{aligned} \quad (5)$$

where  $\gamma^{(j)}$  and  $q_I^{(j)}$  are exogenous

$$I_t^{(j)} = D_{*I}^{(j)} + G_{*I}^{(j)} \quad (6)$$

$$S_t^{(j)} = Q_t^{(j)} - I_t^{(j)} \quad (7)$$

$$C_t^{(j)} = \rho_{1,t}^{(j)} \left[ q_{c,0}^{(j)} - q_{c,1}^{(j)} \cdot P_t^{(j)} + q_{c,2}^{(j)} \bar{P}_{c,t}^{(j)} \right] \quad (8)$$

where  $q_{c,0}^{(j)}$ ,  $q_{c,1}^{(j)}$ ,  $q_{c,2}^{(j)}$  are exogenous

2-2

Table 5-4. Relationships Among Variables (Cont.)

$F_t^{(j)}$	$= \rho_{2,t}^{(j)} [q_{F,0}^{(j)} - q_{F,1}^{(j)} \cdot P_t^{(j)} + q_{F,2}^{(j)} \cdot \bar{P}_{F,t}^{(j)} + q_{F,3}^{(j)} \cdot \bar{P}_{A,t}^{(j)}]$	(9)
	where $q_{F,0}^{(j)}, q_{F,2}^{(j)}$ , and $q_{F,3}^{(j)}$ are exogenous	
$E_t^{(j)}$	$= q_{E,0}^{(j)} \cdot q_{E,1}^{(j)} \cdot P_t^{(j)} + q_{E,2}^{(j)} \cdot \bar{P}_t^{(j)}$	(10)
	where $q_{E,0}^{(j)}, q_{E,1}^{(j)}, q_{E,2}^{(j)}$ are exogenous	
$D_t^{(j)}$	$= C_t^{(j)} + F_t^{(j)} + E_t^{(j)}$	(11)
$\tau P_t$	$= b_0 \Delta(\tau P_{t-1}) + \sum_{\psi=0}^R b_{2\psi} [\tau H_{t-\psi} - \tau L_{t-\psi}]$	(12)
	where $b_0, b_1$ and $b_2$ are exogenous	
$\tau H_t$	$= \sum_{T=0}^m h_{1T} (P_{t-T}) + h_{20} \sigma_t + \sum_{\theta=1}^n h_{30} (\tau H_{t-\theta})$	(13)
$\tau L_t$	$= \sum_{\phi=0}^u a_{1\phi} (\tau P_{t-\phi}) + a_{20} (\tau \sigma_t) + \sum_{\alpha=1}^v a_{31} (\tau L_{t-\alpha})$	(14)

downward rotation of the marginal cost-of-supply schedule, as indicated in Figure 5-5. This modeling assumption is, in actuality, quite complex, and the reader is referred to Chapter 6 of the original ECON report volumes for a full discussion of its meaning. In brief, this effect is based on the observed long-term downward pressure on prices from improved crop forecasts, and particularly on the reduction of price volatility.

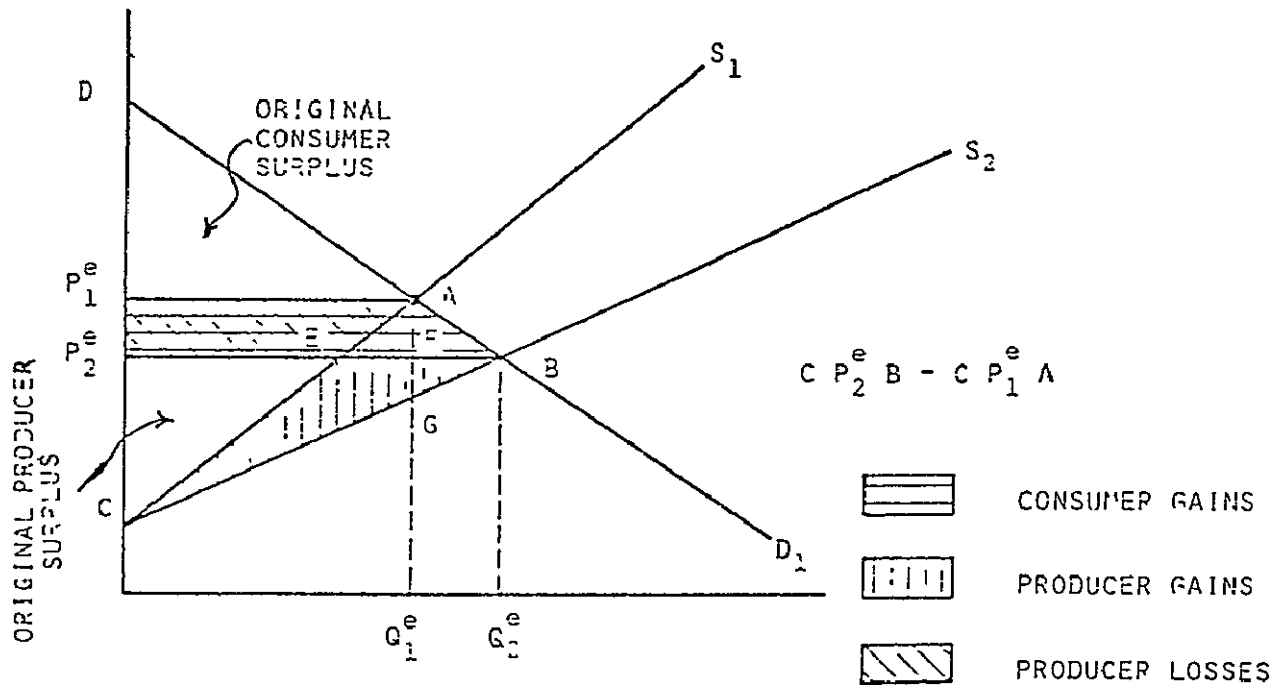


Figure 5-5. Supply Impact of Improved Crop Information on U.S. as Exporter

The model requires variable inputs of the annual crop forecast error variances as functions of: the month when the forecast is published, the country to which the forecast applies, and of course the crop, in this case: wheat. The countries for which specific forecasts are modeled are: Argentina, Australia, Canada, France, Italy, India, South Africa, Spain, UK, USA, USSR. The statistics for the forecast errors are assumed to be in percentage terms. Thus a forecast error statistic (standard deviation) of 5% means that the square root of the second moment of the error distribution of the crop forecast is 0.05 times the true value of the crop production for that country and that year.

The system performance error analysis was done in terms of crop acreage measurement for wheat in the eleven countries mentioned because the satellite systems were presumed to contribute only acreage information. In order to achieve crop production forecast statistics for input to the model, it was necessary to analyze yield per acre statistics and to combine the average yield measurement error with the acreage errors. The manner in which this analysis was performed is described in the following subsection.

#### 5.3.4 TREATMENT OF ACREAGE AND YIELD FOR GLOBAL MODEL

It is assumed for the TOSS study that the satellite system improves the accuracy of early estimates of growing acreage and monitors the crop acreage throughout the crop season. There is no assumed improvement in the measurement of the crop yield per acre. Since the AGR-ECON II model requires estimates of monthly crop forecast standard errors as inputs, it is necessary to construct the estimate in two parts: acreage and yield. If there is independence of the error components due to acreage and yield estimation, then relative standard errors are additive. This assumption needs to be questioned since there are known correlations of error components in practice. However, the reader should be cautioned against confusing the obvious reasons for correlating yield and acreage themselves with the second order effect of a correlation between errors in their estimates. It has been assumed that this effect is small and that we can combine the relative standard errors from each component by simple addition.

To obtain an estimate of the forecast error in yield per acre for each country for each month within the crop year, ECON constructed five-year moving averages for the annual yield forecasts obtained by dividing annual crop production estimates by annual harvested acreage estimates.\* The latter were the only available worldwide crop acreage data and, of course, were a surrogate for estimates of growing acreage. From the moving averages, the standard errors for the annual yield forecasts were estimated, by least squares. These were found to be twice as large for known cases --- e.g. The United States --- as published estimates. The five-year moving average is a weak predictor of yield in countries which experience year to year variations due to weather, crop stress factors and so on, and does not make full use of available meteorological and agricultural information, so it is not surprising that the root mean square error should be too large. To obtain plausible judgmental estimates, ECON divided all the calculated yield error estimates by 2. The resulting yield errors are tabulated in Table 5-5.

The relative standard error was then taken to apply to the forecasts which were made early in the crop year, i. e. when the crops were just beginning to be visible above ground. From that point in time to completion of harvest, it was assumed that the relative standard errors of the yield forecasts decline linearly to zero for each country. Thus the contribution of the yield component to the total wheat crop production forecast error begins at about 50% in May for the U.S., declining gradually to zero in October.

This rather simple model is not advanced as an authoritative research effort on the question of allocating crop forecast errors to yield and acreage estimation. Rather, it is an adequate representation of the known facts in view of the concomitant level of sophistication in the analysis of the crop acreage estimation errors, as well as in the analysis of economic effects of the forecast errors.

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\*To the extent that acreage and production estimates are accurate this method gives yield per harvested acre. Except for the U.S. and Canada, no other yield per acre figure is available. For instance, it would be helpful to use seeded acreage to get yield per seeded acre estimated.

Table 5-5. Relative Standard Yield Error

Country	One-Sigma Yield Error (%)
1. USA	6.0
2. USSR	9.6
3. UK	4.9
4. Canada*	9.1
5. Argentina	8.4
6. Australia	9.4
7. Spain	6.4
8. France	4.9
9. Italy	4.9
10. India	8.1
11. S. Africa	9.8

Source: ECON, Inc. based on 1960-1974 Monthly Grain Bulletin

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\*The high estimate for Canada is affected by the two drought years included in the data interval.

**APPENDIX A**  
**U.S. CROP SURVEY ECONOMETRIC MODEL**

## APPENDIX A

### U.S. CROP SURVEY ECONOMETRIC MODEL

Over the past several years, ECON has performed studies designed to estimate the economic value of information of the type obtainable from remote sensing platforms. In 1975, an ECON study contracted by NASA examined the benefits of crop acreage measurement information as the quality of that information improved. This parametric study has been used to provide evaluations of alternative system configurations and design details for the TOSS project.

Being strictly a benefit study, ECON's work did not provide estimates of the costs of providing information of the differing qualities. In fact, ECON's study was not concerned with the source of the information at all, for information was considered only in the abstract. That is, the attributes of an information system were characterized only in terms of economic parameters, e.g., accuracy of acreage measurement and timeliness of the information. Consequently, it was necessary in a treatment of an operational system to forge a link between economic capability and the engineering system attributes (e.g., IFOV, number of platforms) required to produce that capability. This latter role has been played by General Electric Space Division.

In this section we will briefly summarize ECON's modeling effort and describe the input parameters used in the U.S. Crop Survey model. Any synopsis of this type must be very sketchy and we will only make note of the main steps in the formulation and solution. The reader interested in more detail is referred to the original documentation by ECON.\*

#### A.1 OVERVIEW OF U.S. CROP SURVEY MODEL

(This section includes some non-transparent mathematical presentation. The reader merely interested in general concepts need only read the first half of Section A.1 and skip to Sections A.2 and A.3, noting Equations 1-2 and 1-3 in passing).

Information about the current state of the growing crops in the U.S. is used to formulate crop production forecasts, which, in turn, are used by inventory holders to decide upon the rate of inventory depletion which maximizes their profit. Given competitive economic conditions, it can be shown that this profit-maximization behavior on the part of inventory-holders is also optimal from the point of view of consumers in the aggregate. The subject of this model, then, is the effect of improved information about current crop status upon consumer welfare and, in particular, the type of information analysed is the measurement of currently growing crops, by crop type.

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\*Andrews, John, "The Value of Domestic Production Information in Consumption Rate Determination for Wheat, Soybeans, and Small Grains," ECON, Inc. Report No. 75-127-3. 31 August 1975.



The modeling approach taken is one of optimal control processes, where the value of present and future consumption is maximized subject to current consumption. (Consumption rates and inventory depletion rates are considered to be two sides of the same process). Specifically the formulation and the algorithm for solution are those of dynamic programming. Figure A-1 illustrates this overview. The central relationship is the linear differential equation describing the supply system

$$\frac{dS}{dt} = \frac{dH}{dt} - \frac{dC}{dt}$$

Where C and H are accumulated consumption and production, respectively, and S is remaining supply. The decision-maker obtains information about S from a measurement system, and exhibits partial control over S by selecting  $\frac{dC}{dt}$ .  $\frac{dC}{dt}$  is optimized, then, subject to the state of information concerning S.

$S_n$ , representing the state of the system at  $t_n$ , is the mean of a probability distribution of the eventual actual production less accumulated consumption. As time advances to  $t_{n+1}$  from  $t_n$ ,  $S_n$  is decreased by the consumption  $C_n$  and changed by a random term  $\phi_n$ , reflecting new information and past, current, or future monthly harvests. To formalize this process, we define the state transformation

$$T_n(x, y) = x - y + \phi_n, \quad n = 0, \dots, m-1 \quad (1-1a)$$

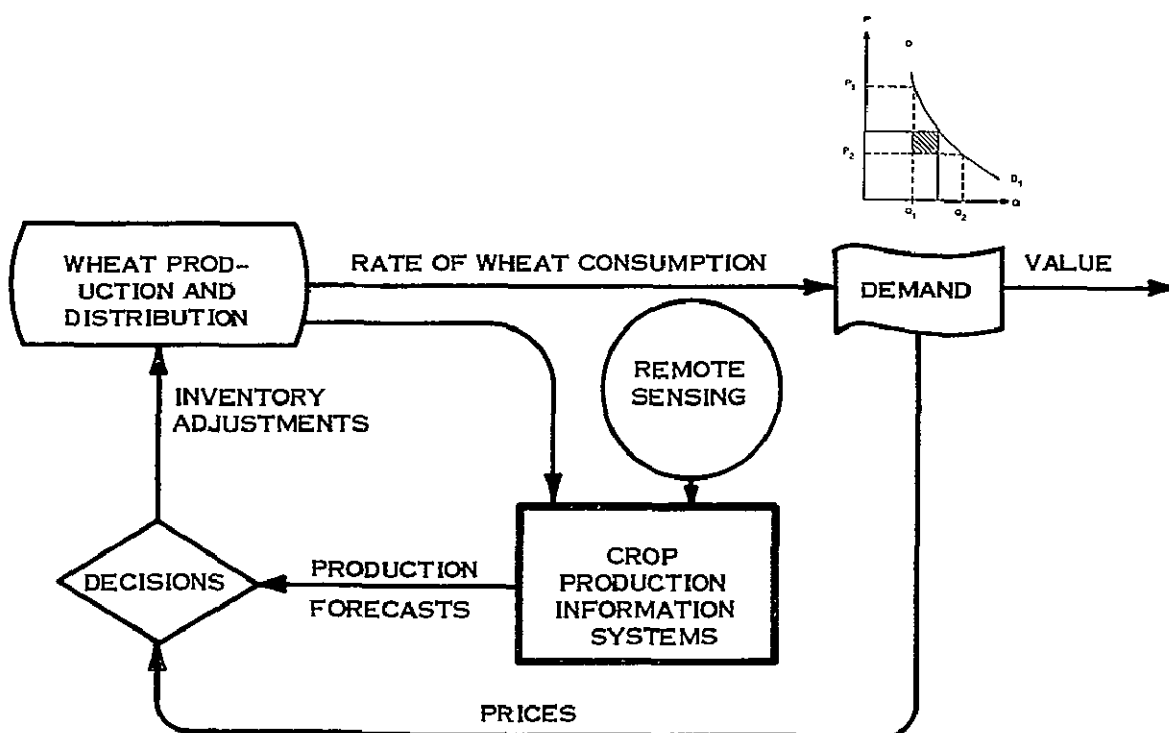


Figure A-1. Overview of Dynamic Model

where  $x$  and  $y$  are non-subscripted dummy variables.

$$\text{or } S_{n+1} = T_n(S_n, C_n) = S_n - C_n + \phi_n \quad (1-1b)$$

The random term  $\phi_n$  is assumed to have a mean at time  $t_n$  of zero.\*

Letting  $F_n(y)$  represent the integral of the demand function from zero to  $y$  (i.e., the economic value of consumption during  $t_n$ ), the principle of optimality for this process is

$$V_n(x) = \max (F_n(y) + \rho \overline{V_{n+1}(T_n(x, y))})$$

The bar denotes the mean with respect to one period's uncertainty, that of  $\phi_n$ . The factor  $\rho$  is the discount factor; if  $r$  is the discount rate,  $\rho = \frac{1}{1+r}$ . By assuming a quadratic form for  $F_n(y)$ , it is possible to derive

the following equation for mean annual economic loss:\*\*

$$L = k \sum_{n=1}^{m+1} E_n \sigma_{n-2}^2 \quad (1-2)$$

$$\text{where } E_n = \begin{cases} \frac{r}{(1+r)^m - (1-r)^{n-1}}, & n = 1, \dots, m \\ \frac{1}{(1+r)^{m-1}}, & n = m+1 \end{cases}$$

$m$  = the number of decision periods in one year (assumed in the study to equal 12)

$k$  = minus one-half times the slope of the demand function with price based on monthly consumption quantities,\*\*\*

The  $\sigma_n^2$  terms are the period (monthly) production forecast variances, i.e., the variance of the random  $\phi_n$  terms from Equation 1-1. It yet remains to show the relationship between the selected input parameters, accuracy and timeliness, and  $\sigma_n^2$ .  $\phi_n$  is the way in which estimates of potential production change over time:

$$\phi_n = \hat{P}_{n+1} - \hat{P}_n$$

where  $\hat{P}_n = S_n + C_n$ .  $P_n$  (actual potential production) is the measurable state of the system.

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\*For details of the derivation, see the source document, Chapter 3.

\*\*This formulation of the problem is directly analogous to other processes with which engineers may be familiar. For an elementary example, one may be interested in how the pressure of a closed container (pressure being one state variable representing the state of the system) changes over time as some control variable (say, heat) is manipulated. The state transformation would define the state in the next time period by the state and the control employed at present

$$P_{t+1} = T P_t, Q_t$$

\*\*\* $k$  has been estimated in econometric work previously performed by ECON.

$$P_n = P(t_n - \tau)$$

where  $\tau$  is the data availability lag (the timeliness input parameter). The sequence  $\{P_n\}$  has the random difference term  $\epsilon_G(n)$  which has a zero mean and variance  $\sigma_G^2(n)$  (which is possible to estimate from USDA crop statistics).  $\hat{P}_n$  is obtained from  $P_n$  by measurements which have a random measurement error of  $\epsilon_M(n)$ , with zero mean and variance of  $\sigma_M^2(n)$ . This relationship is shown in Figure A-2. We can now obtain a value for  $\phi_n$ :

$$\begin{aligned}\phi_n &= \hat{P}_{n+1} - \hat{P}_n = P_{n+1} + \epsilon_M(n+1) - P_n - \epsilon_M(n) \\ &= \epsilon_G(n) + \epsilon_M(n+1) - \epsilon_M(n)\end{aligned}$$

and for  $\sigma_n^2$ :

$$\sigma_n^2 = \sigma_M^2(t_n - \tau) + \sigma_G^2(t_n - \tau) + \sigma_M^2(t_{n+1} - \tau)$$

Let us define  $\epsilon$  to be the ratio of the standard deviation of the error in measuring  $P_n$  to  $P_n$  when  $G(t_n) = 1$  ( $G(t_n)$  refers to the growing fraction of the crop so that when  $G(t_n) = 1$ , the whole crop is planted and none yet harvested).  $\epsilon$  is chosen to be the input parameter representing accuracy. By assuming  $\sigma_M^2(t_n)$  to be proportional to  $G(t_n)$ , we get:

$$\sigma_M^2(t_n) = \epsilon^2 H^2 G(t_n)$$

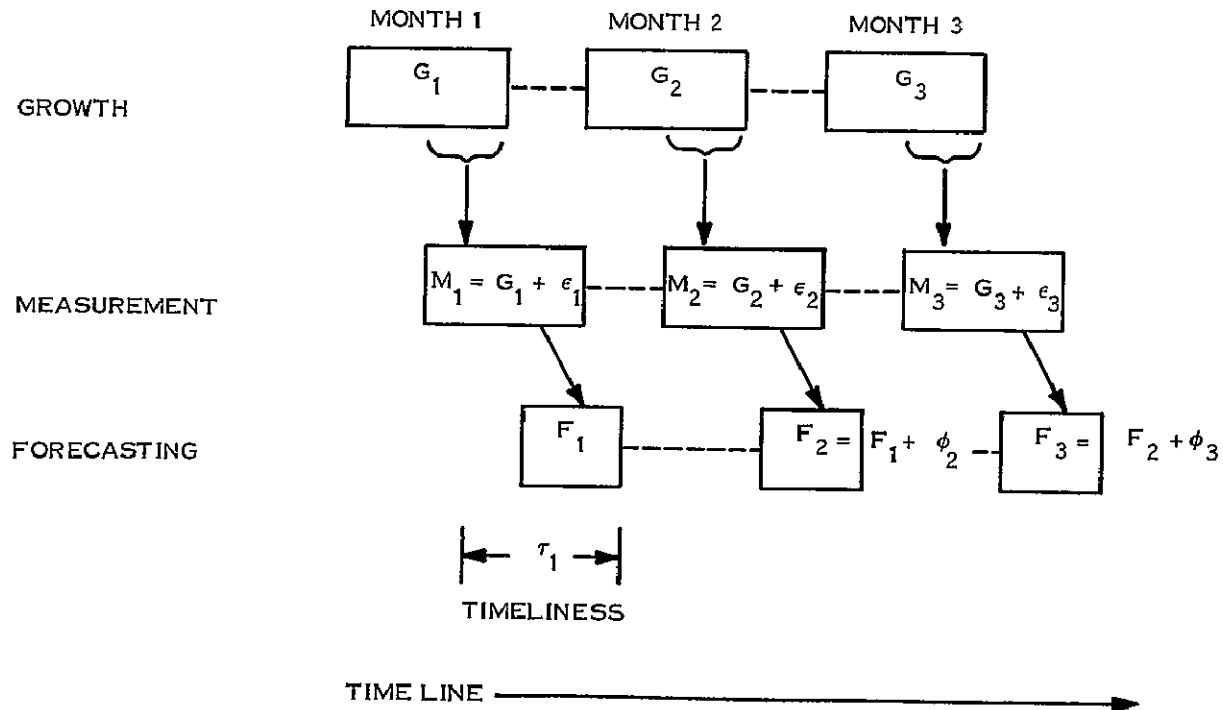


Figure A-2. Overview of Harvest Information Process

where  $H$  is average annual production. Now by assuming the variance of  $\frac{P_{n+1}-P_n}{A_p}$  to be proportional to the square of  $G(t_n)$ , it can be shown that:\*

$$\sigma_m^2 = \begin{cases} \frac{G^2(t_m - \tau)}{\sum_{i=-12}^{12} G^2(t_i)} A_p^2 \text{Var}_G + H^2 \left[ G(t_m - \tau) + G(t_{m+1} - \tau) \right] \epsilon^2, & m \geq 0, \\ \frac{\sum_{i=-12}^{-1} G^2(t_i - \tau)}{\sum_{i=-12}^{12} G^2(t_i)} A_p^2 \text{Var}_G + H^2 G(t_0 - \tau) \epsilon^2, & m = -1 \end{cases} \quad (1-3)$$

where

$A_p$  is the historical mean of the planted acreage.

$\text{Var}_G$  is the historical variance of annual production per planted acre.

$H$  is the historical mean of annual production.

$G(t_m)$  is the historical mean of the growing fraction of annual production at time  $t_m$ .

Thus we have obtained the link between economic loss (Equation 1-2) and the measurement system input parameters,  $\epsilon$  and  $\tau$ . Since it is important to understand the meaning of these parameters, we will devote a little more space toward a discussion of them.

## A.2 THE INPUT PARAMETERS

The accuracy of the measurement system, represented by  $\epsilon$ , is expressed as a percentage error: the ratio of the standard deviation of the measurement error of potential production to true potential production consequently,  $\epsilon$  is also equivalent to the percentage error in the measurement of growing acreage, so long as the prediction of yield per acre is held fixed. Similar to current USDA practices, it is necessary to assume that data concerning the relationship between currently growing acreage and final production yield per growing acre is obtained independently. It is important to note that  $\epsilon$  is not a crop forecast error.

$\tau$  is the total time between when the actual measuring processes are performed and when the decision-maker (here, the inventory holder) has the information (growing acreage or production estimates). In applying this parameter to a satellite-based information system, an average value of  $\tau$  is used, given by

\*See Chapter 4 in the source document for details.

$$\tau = \frac{1}{2} \delta t + \theta$$

where  $\delta t$  is the time interval between measurements and  $\theta$  is the report preparation time.

### A.3 RESULTS

Using USDA data, loss functions were plotted separately for wheat, soybeans and aggregate small grains, by means of Equations 1-2 and 1-3. Presented here in Figure A-3 is the plot for wheat.

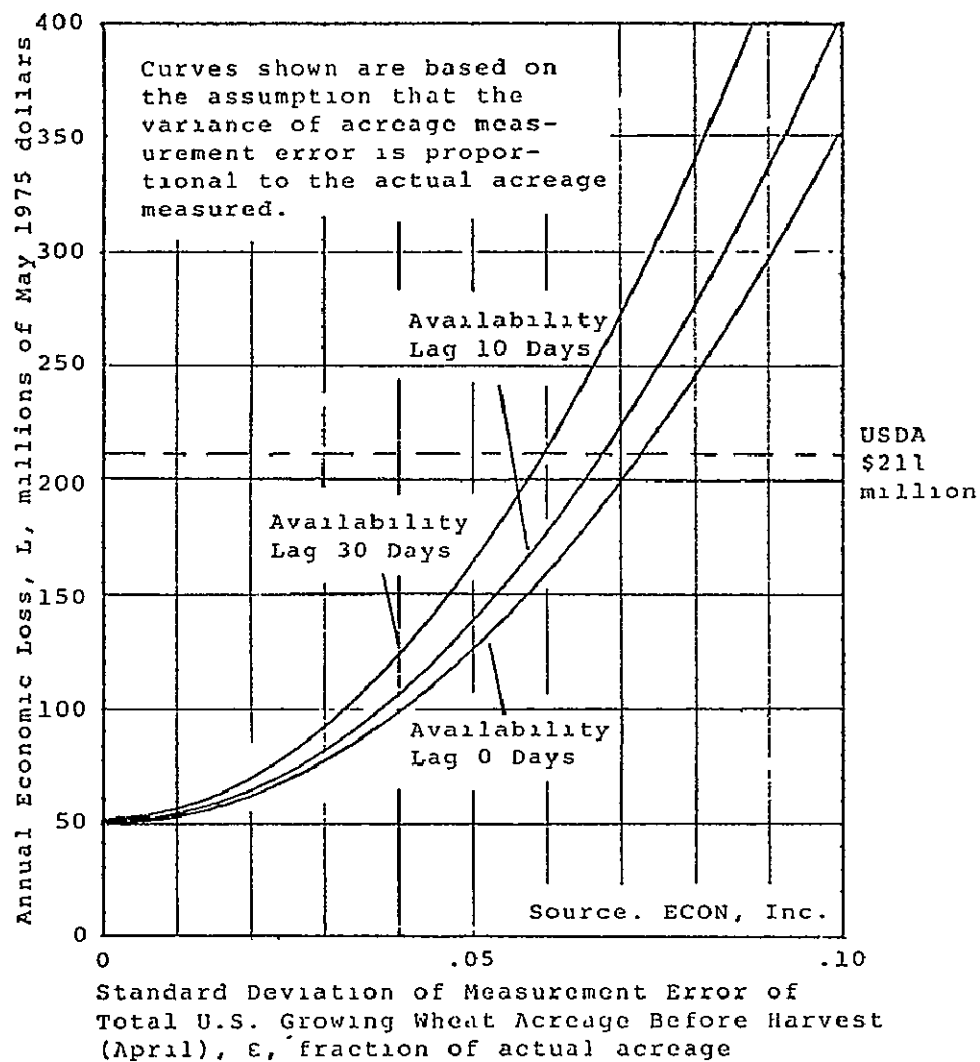


Figure A-3. Annual Economic Loss Due to Imperfect Wheat Production Forecasts

**APPENDIX B**  
**ECONOMIC LOSS ASSOCIATED WITH THE**  
**CURRENT USDA CROP REPORTING SYSTEM**

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APPENDIX B  
ECONOMIC LOSS ASSOCIATED WITH THE CURRENT USDA CROP  
REPORTING SYSTEM

In studying the potential economic benefits of various space systems providing information on growing crops, it is useful to analyze the well-established system currently operated by the USDA. In fact, it is most practical to apply the results of the kind of economic analysis that has been accomplished to date as follows. One first builds a model which calculates the economic loss to the economy associated with each specified performance level of the agricultural information system. The performance level can be quantified, for example, in terms of selected average errors of measurement, of estimate, or of forecast. Then the benefit of one information system compared to another is taken as the difference between the economic loss associated with one system and the economic loss associated with the other. With this approach, one cannot estimate the benefits of a new system without first estimating the losses associated with the current system.

The Distribution Benefits Model

One of ECON's economic models has been applied in this way to the question of the economic benefits to the United States of growing acreage measurements of the United States wheat and soybeans crop.\* In this analysis, the United States agricultural sector is treated as if isolated from that of the rest of the world, and the only losses studied are those due to inefficient temporal distribution of the crops. Consequently, the economic losses treated are likely to be an understatement of the true losses to the economy.

The central result of the "distribution" study is the following equation.

$$L = k \sum_{j=1}^{13} E_j \sigma_{j-2}^2 \quad (1)$$

Here,  $L$  is the annual economic loss,  $k$  is minus one half the slope of the (demand) function giving price as determined by monthly consumption,  $E_j$  are constants discussed below, and  $\sigma_j^2$  are variances used to describe the performance of the information system. These variances are not simply error variances, but are conditional forecast variances defined as follows. At a given time  $t_j$  of the crop year beginning at  $t_0$  and ending at  $t_{12}$  the available information on the year's total production is summarized by a production estimate (we use this word for both forecasts and estimates of accomplished production). Just after publication of such an estimate, say  $F_3$  at time  $t_3$ , one would have to regard the next monthly estimate,  $F_4$ , as an unknown quantity with a mean value equal to  $F_3$  and some variance,  $\sigma_3^2$ . Thus, for each  $j = 0, 1, \dots, 10$ ,  $\sigma_j^2$  is the variance at time  $t_j$  of the next monthly estimate, which is due to be published at

\*Andrews, John, The Value of Domestic Production Information in Consumption Rate Determination for Wheat, Soybeans, and Small Grains, ECON, Inc., Report No. 75-125-3, August 31, 1975.



time  $t_{j+1}$ . We assume that the market discovers the true annual production by the end of the crop year, time  $t_{12}$ . Accordingly,  $\sigma_{11}^2$  is the variance at time  $t_{11}$  of the true production for the year. Finally,  $\sigma_{-1}^2$  is the variance at a time before harvest begins of the estimate published at time  $t_0$ .

Notice that each of the variances  $\sigma_j^2$  will be zero, and the loss  $L$  will be zero, if and only if the information system is able to correctly predict the true production for the year from the beginning of the crop year.

The coefficients  $E_1, \dots, E_{13}$  appearing in the loss equation are given by the following formula, in which  $r$  is the monthly (risk-free) discount rate prevailing in the economy.

$$E_j = \begin{cases} \frac{r}{(1+r)^{12} - (1+r)^{j-1}}, & j = 1, \dots, 12 \\ \frac{1}{(1+r)^{11}}, & j = 13. \end{cases} \quad (2)$$

Numerical values of  $E_j$  corresponding to  $r = .005$  are given in Table B-3.

#### Application of the Model

In applying our model (Equation 1) to the current USDA crop reporting system, we find an abundance of relevant data in the form of the month-by-month estimates published in Crop Production in recent years. To see how these data are to be used, consider a particular time  $t_j$  within a future crop year. A wheat market agent at the time  $t_j$  can base the quantification of his state of uncertainty of the forthcoming production estimate  $F_{j+1}$  on the historical variability of the  $t_{j+1}$  estimate. Ideally, he would calculate the variance of this estimate over a set of years in which the time  $t_j$  estimate were the same as that of the current year. Furthermore, the selected years would be very recent in order that the data represented the performance of the same kind of procedures and skills currently used in preparing production estimates. Of course, such an ideal set of data does not exist. As a substitute, one can use all of the estimates of recent years, together with the assumption that month-to-month estimate differences (such as  $F_{j+1} - F_j$ ) tend to be proportional to the size of the year's crop. We use this assumption here, and measure the crop size by seeded acreage.\*

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\*Other measures are defensible, but this one fits simply into our theoretical structure, in which both true production and estimates thereof are modeled as stochastic processes which begin at seeding time.

Accordingly, we have collected from Crop Production the USDA monthly estimates of annual wheat and soybeans production, together with the later revisions, and the final reports of planted acreage. These are given in Table B-1 and Table B-2. Sixteen years of data are shown, from the years 1959 to 1974.

$\sigma_j^2$  is estimated for a given year (indexed n) in which planted acreage is  $A_p^n$  as

$$\sigma_j^2 = (A_p^n)^2 V_j$$

where  $V_j$  is the historical variance of

$$\Delta Y_j = \begin{bmatrix} \frac{S_{j+1} - S_j}{A_p} & j = 0, 1, \dots, 11 \\ \frac{S_0}{A_p} & j = -1 \end{bmatrix}$$

The variances  $V_j$  are calculated from the 16 years of data given in Table B-1 and Table B-2. The results are shown in Table B-3, together with the calculations of the mean economic loss. The value of  $A_p^n$  is taken as the mean of planted acreage over the period of 1961-1970.\* These figures are 55.6 millions acres for wheat and 35.9 million acres for soybeans.

The results of applying Equations (1) and (2) to the USDA reports given in Tables B-1 and B-2 are as follows: for wheat, the annual loss is \$ 211 million (May 1975); for soybeans, the annual loss is \$ 39 million (May 1975).

In order to express the economic loss as a function of a single system parameter relating to accuracy (the other necessary parameter in this case relates to timeliness) ECON recalculated the loss equation for 4 separate values of timeliness as a function of the G.E. parameter  $\sigma_M$ . The latter is the percentage error of acreage measurement when growing crops are first measured, early in the season. Assuming a flat temporal distribution of errors of acreage measurement it is possible to derive the correct form of the relationship between loss and errors so that the restriction to early season measurement is removed. This derivation was done and the results are shown in Figure B-1. By selecting the appropriate timeliness value for USDA crop reporting ( $\tau = 10$  days approximately) one can obtain the baseline value of  $\sigma_M$  associated with an economic loss of \$ 211 million annually i. e.,  $\sigma_M = 8\%$ . It needs to be emphasized that this is not the same as saying that the forecast of crop production has 8% error, but it is merely a reference point to establish the baseline performance required of operational systems to produce benefits.

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\*For consistency with the distribution study, op. cit. Page 2-2.

Table B-1. Monthly and Final Reports of Annual Production of all Wheat

Monthly and Final Reports of Annual Production of All Wheat Published by the USDA, and Planted Acreage 1959-1974									
Year	Planted Acreage (Millions)	Annual Production (Millions of Bushels)							
		Jun 10	Jul 10	Aug 10	Sep 10	Oct 10	Dec 10	1 Year Later	Jan 1975
1959	56.7	1182	1155	1110	1116	1117	1128	1127	1118
1960	54.9	1211	1347	1362	1368	1368	1363	1357	1355
1961	55.7	1343	1059	1204	1210	1211	1235	1235	1232
1962	49.3	1058	1050	1063	1096	1095	1092	1094	1092
1963	53.4	1084	1111	1151	1234	1153	1137	1142	1147
1964	55.7	1213	1275	1235	1290	1286	1290	1291	1283
1965	57.4	1283	1354	1376	1358	1354	1327	1316	1316
1966	54.1	1235	1240	1286	1295	1296	1311	1312	1305
1967	67.3	1550	1596	1511	1543	1554	1524	1522	1508
1968	61.9	1230	1588	1606	1597	1598	1570	1576	1557
1969	53.5	1161	1425	1459	1457	1456	1459	1460	1443
1970	48.7	1076	1349	1357	1360	1360	1378	1370	1352
1971	53.8	1478*	1548	1601	1625	1628	1640	1618	1618
1972	54.9	1547*	1551	1543	1559	1559	1545	1545	1545
1973	59.0	1745*	1740	1717	1727	1727	1711	1705	1711
1974	71.2	2053*	1925	1894	1792	1781	1793	—	1793
* Publication for all wheat discontinued. This figure is forecast for winter wheat plus first published spring wheat forecast.									

B-4

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Table B-2. Monthly and Final Reports of Annual Production of Soybeans

Monthly and Final Reports of Annual Production of Soybeans Published by the USDA, and Planted Acreage 1959-1974								
Year	Planted Acreage (Millions)	Annual Production (Millions of Bushels)						
		Aug. 10	Sep 10	Oct. 10	Nov 10	Dec	1 Year Later	Jan 1975
1959	23.3	531	533	530	528	538		533
1960	24.4	548	566	562	560	559	555	555
1961	27.8	683	720	710	701	693	680	679
1962	28.4	703	669	672	669	675	669	669
1963	29.4	723	728	727	718	701	699	699
1964	31.7	748	704	699	702	700	702	701
1965	35.2	864	867	862	853	844	846	846
1966	37.3	860	926	927	929	931	928	928
1967	40.8	999	1003	994	985	973	976	976
1968	42.3	1064	1080	1066	1079	1080	1103	1107
1969	42.5	1061	1055	1070	1094	1117	1126	1133
1970	43.8	1114	1133	1135	1134	1136	1124	1127
1971	43.5	1235	1186	1175	1200	1169*	1176	1176
1972	46.9	1270	1286	1317	1351	1276*	1271	1271
1973	57.3	1540	1599	1588	1575	1567*	1547	1547
1974	55.0	1314	1316	1262	1244	1233*	—	1233
* Release date moved from mid-December to mid-January.								

Table B-3. Calculation of Mean Economic Loss Associated with USDA

Calculation of Mean Economic Loss Associated with USDA Crop Reporting System. Wheat and Soybeans.			
Month Index j	Coefficient $E_{j+2}$	Variance ( $V_j$ ) of $\Delta Y_j$ (bu <sup>2</sup> /acre <sup>2</sup> )	
		Wheat	Soybeans
-1	.0811	10.35	2.54
0	.0882	7.57	0.75
1	.0968	0.75	0.12
2	.1073	0.36	0.12
3	.1204	0.23	0
4	.1373	0	0.25
5	.1597	0.09	0
6	.1912	0	0
7	.2384	0	0
8	.3171	0	0
9	.4745	0	0
10	.9466	0	0
11	.9466	0.03	0.07
$\sum_j E_{j+2} V_j$		1.69 bu <sup>2</sup> /acre <sup>2</sup>	401 bu <sup>2</sup> /acre <sup>2</sup>
$\times (A_p^n)^2 = \sum_j E_{j+2} \sigma_j^2$		$\times 3.10 \times 10^{15} \text{ acre}^2 = 5.23 \times 10^{15} \text{ bu}^2$	$\times 1.29 \times 10^{15} \text{ acre}^2 = 5.17 \times 10^{14} \text{ bu}^2$
$\times k = L$		$\times 4.04 \times 10^{-8} \$/\text{bu}^2 = \$211 \text{ million}$	$\times 7.5 \times 10^{-8} \$/\text{bu}^2 = \$32.8 \text{ million}$
Source ECON, Inc.			

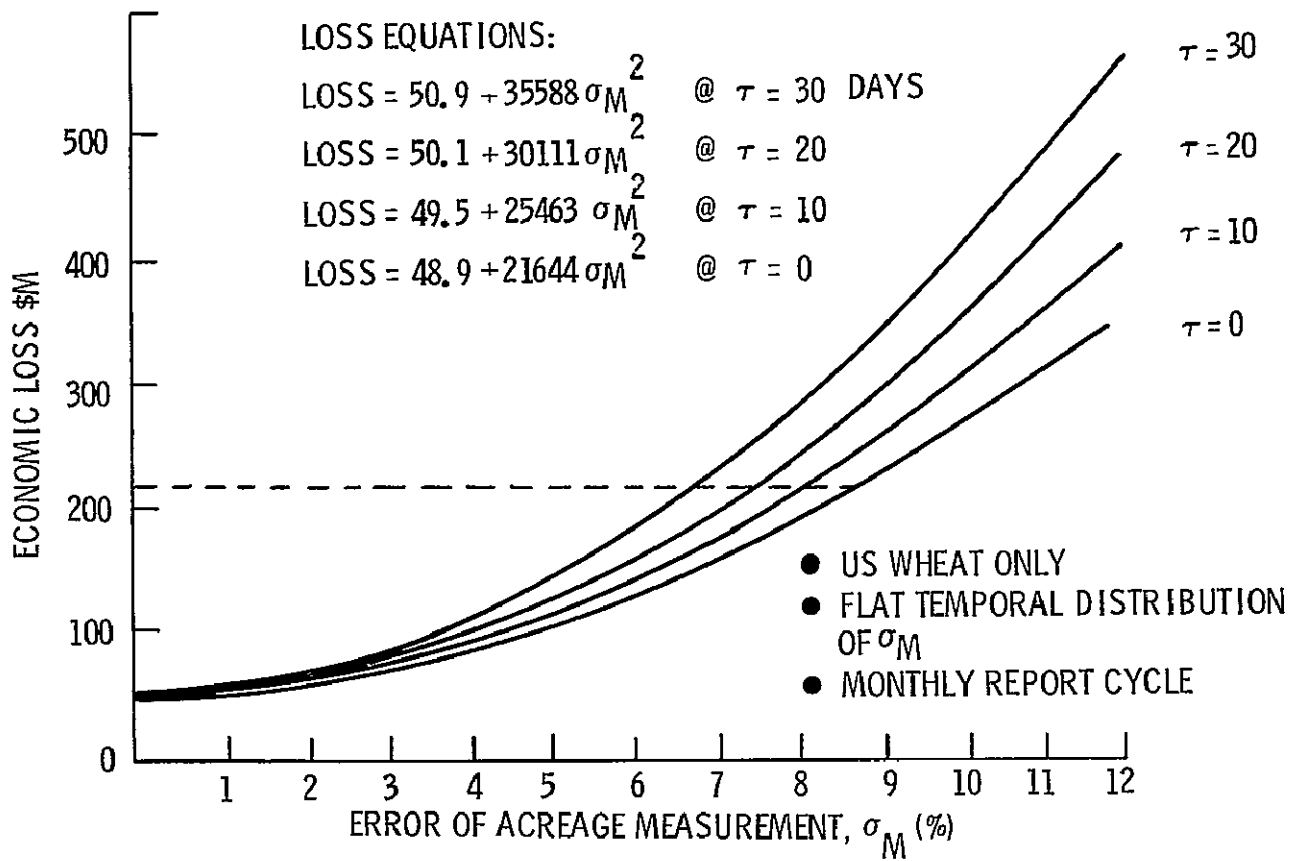


Figure B-1. The Economic Loss as a Function of the GE Parameter for Accuracy of Crop Measurements

**APPENDIX C**  
**U.S. CROP SURVEY MISSION**

**APPENDIX D**  
**WORLD CROP SURVEY MISSION**

## PREFACE

The TOSS effort investigated two agriculture survey missions: U.S. Crop Survey and Global Crop Survey. These two missions are quite different in their scope and acquisition of data (particularly ancillary data); yet at the same time, they are quite similar in their information processing and implementation systems. This Appendix will address these two missions and the derivation of their TOSS mission requirements.

Except for the discussion of the Statistical Reporting Service, which deals with the production of agricultural statistics for the U.S., most of the material in this appendix applies to both the US and Global missions. A more detailed discussion of the Global Crop Survey mission and its requirements is continued in the TERSSE Final Report Volume 5, Detailed System Requirements Two Case Studies.

Although the material in this appendix represents both Appendix C, U.S. Crop Survey Mission and Appendix D, Global Crop Survey Mission the pages and section numbers use only the "C" nomenclature.



## C.1 UNDERSTANDING THE CROP MISSION

Agriculture, America's biggest business, requires accurate information and reliable evaluations concerning production, supplies, marketing, prices, exports, and a vast array of other inputs if it is to operate efficiently, effectively, and profitably. A successful agribusinessman today, whether he is a farmer or an international grain company president, is a combination of highly skilled technician and executive who frequently needs to apply more expertise and make more demanding decisions than a manager of a factory or other business.

The uses of agricultural statistical information are extensive and varied. although the impact of crop and other data on a given agribusiness depends on the type and size of the operation, a main user of agricultural information is certainly the producer. To cash-crop farmers, with more alternatives in planning crop acreage than those producing feed crops for use on the farm, early-season indications of acreage planted nationally and regionally are quite useful. Producers of crops that can be stored are confronted with finding the best market opportunity, and information on production and stocks is valuable. Producers of perishable crops are interested in the timing of plantings and the acreages planted, as an indication of market flow during the marketing period.

Other important users of agricultural statistics are farm organizations, State and national farm policymakers, and foreign buyers of agricultural products. Use of data by farm groups ranges from simple distribution indications to preparing an important marketing campaign. Farm supply firms also rely heavily on statistics when planning purchases and sales of feed,

fertilizer, machinery, fuel, seed, and other farm production items. For those engaged in marketing, processing, and distributing agricultural products, supply and demand information is useful in linking producer and consumer.

Government agencies at various levels are important users of statistics. Federal farm programs, in all their different forms, require information on acreages, production potential, stocks, prices, and income. Agricultural statistics are used in planning and administering other related Federal and State programs in such activities as consumer protection, conservation, recreation, foreign trade, and education.

Although perhaps not separate and distinct from the categories of those already mentioned, the role of the analyst as a user of statistics should be recognized. The analyst in Government, universities, agribusiness, and farm organizations transforms statistics into projections of current trends, interprets their economic implications, and evaluates alternative courses of action in terms of prospective outcomes. Their projections, in turn, affect producers.

Those in agriculture, those associated with agriculture, and those relying on agriculture's food and fiber output benefit from crop statistics, because such data help develop a stable atmosphere for production, marketing and distribution operations.

Two of the most important types of crop statistics to a wide range of users are acreage and yield. Acreage measurements pertain to the amount of land occupied by a particular crop. Yield measurements pertain to the amount of output per unit of area - such as the bushels of corn produced per acre. Yield is a variable throughout the growing season, however, in that crops -

like any other plants - are susceptible to a variety of stress factors that affect their productivity. Together, acreage and yield statistics are used to generate estimates and forecasts of production, these estimates being tempered by observations of acreage actually harvested. The focus of TOSS is on the preparation of such production forecasts and estimates for seven major crops; namely, wheat, corn, soybeans, rice, oats, barley, and rye.

Under TOSS, the primary source of crop information input will be satellite data; however, the role of the Statistical Reporting Service (SRS) as the fact-collecting and reporting organization of the U.S. Department of Agriculture responsible for preparation of national and State crop forecasts/estimates and related statistical data will be maintained.

#### C.1.1 SRS - STATISTICAL REPORTING SERVICE

SRS is a broad-based, nonpolicy making organization headquartered in Washington, D.C., with State Statistical Offices serving all States. Responsibilities are shared by the Research, Survey, and Estimates Divisions, the Crop Reporting Board, and the State Statistical Offices (SSO's).

The primary functions of the Research Division are to develop new and improved collecting, estimating, and forecasting methods for agricultural statistics and to encourage the use of sound statistical techniques throughout USDA. It performs methodological research, conducts consumer preference surveys, and obtains approval from the Office of Management and Budget for USDA survey plans and questionnaires.

The Survey Division is responsible for preparing and establishing procedures used by the SSO's in collecting data by mail and enumerative surveys, and

for the objective yield measurement program. The Division designs and tests survey techniques, including forms and questionnaires, writes data collection instructions, and conducts training schools for enumerators. Much survey information is processed by the Division using the USDA's computer facility, with the summaries produced being used by the State Statistical Offices and Crop Reporting Board in setting official estimates.

The Estimates Division is the primary source in SRS for agricultural statistics, including their analysis and interpretation, for use by the Crop Reporting Board in making estimates and forecasts of the Nation's agriculture. The Division evaluates commodity statistics, determines needs, and implements proper statistical plans in support of the crop reporting program, and ensures that appropriate methods and procedures are used in all phases of the program. It has the responsibility for defining data inputs and outputs and serves as the principal contact point with data users.

The Crop Reporting Board reviews and adopts official State and National estimates for crops as required by USDA regulations. Unlike the divisions discussed above, the Board is not a fixed element of SRS, but is convened periodically. Permanent members of the Board include the Deputy Administrator of SRS, who serves as Board Chairman, the Director of the Estimates Division, who is the Vice Chairman, and the Chief, Data Services Branch, Survey Division, who serves as Secretary. In addition to these permanent members, five or six commodity specialists are selected by the Chairman from the Estimates Division and the State Statistical Offices to participate in estimate determinations. State representation on the Board changes for each report, both to provide representation of all portions of the country and to assure that statisticians with first-hand knowledge of the important

producing areas contribute to the final determination of the forecasts and estimates.

The State Statistical Offices (SSOs) are the primary data collecting, processing, evaluating, and estimating units of SRS. They maintain contact with the States' agricultural community and, following prescribed procedures, conduct surveys and recommend statistical estimates for their States and counties to the Crop Reporting Board. These estimates, after Board review and adoption, become part of the national, State, and country data series.

Forty-four SSO's serve the fifty states. The six New England States are handled from one office in Boston. Maryland and Delaware are handled from one office in College Park, Maryland. Elsewhere, there is an office in each State. This decentralized approach for making estimates is based on the assumption that statisticians located in the SSO's can best adapt general procedures to the varied local circumstances and have a far better grasp of regional conditions affecting agriculture.

In general, the progression of acreage estimates is from prospective plantings to acreage intended for harvest to acreage actually harvested. Most spring-sown crops follow this sequence: (1) acreage intended for planting as of March 1, released about mid-March; (2) acreage planted and acreage for harvest, released with the mid summer report; and (3) acreage planted and harvested, released in the Annual Crop Production Summary in January following the growing season. Fall-sown rye and winter wheat depart from this sequence, with seeded acreage estimated in December of the year preceding harvest, and winter wheat acreage for harvest in May of the harvest year.

Forecasts and estimates of yield and production are usually provided as of the first of each month during the harvest year growing season, for spring-sown crops the range generally being July 1 to Nov. 1 and for winter wheat the range being May 1 to Sept. 1. It should be noted that forecasts and estimates are two distinct concepts when used to indicate yield and/or production. Forecasts refer explicitly to expectations of yield or production on the basis of known facts on a given date, assuming weather conditions and damage from insects or other pests during the remainder of the growing season will be about the same as the average of previous years. Thus, even if potential based on current conditions were appraised accurately, changes in weather or other conditions could make the actual outcome differ from the forecast. Estimates refer to a measure of accomplished fact, such as crop production at or after harvest time.

Forecasts of production for corn, wheat, oats, cotton, soybeans, and sweet oranges are defined by law as "speculative". Since these commodities are heavily traded in the futures market, anyone having access in advance to the official forecast of production would have clear advantages. Reports of survey data on the speculative commodities from the major producing States go through the mails (from the SSO's to SRS Headquarters in Washington, D.C.) in distinctive envelopes and receive special handling. When they arrive in Washington, they are placed into a special steel box that is secured with two separate locks. One key is retained in the Office of the Secretary and the other is in the custody of the chairman of the Crop Reporting Board.

Early in the morning on crop report day, the Chairman of the Crop Reporting Board and a representative of the Secretary, under armed guard, open the box, remove the reports, and take them to the Board Rooms.

While crop reports are being prepared, the Board rooms are locked and placed under uniformed guards who also patrol the area outside the lockup quarters. The window blinds are closed and sealed, and all telephones are disconnected. Food is sent in to the employees. There is no communication out of the area.

Strict security precautions are also imposed for reports designated as "non-speculative." Although not prepared behind locked doors, material for these reports is worked on in restricted areas and access by unauthorized persons is denied. These estimates, too, are reviewed by the Crop Reporting Board before release.

Minutes prior to release time, the Chairman, Secretary, and a limited number of Board members take copies of the report to the newsroom outside the locked area. No communication with anyone is permitted. Reporters from wire services, newspapers, radio, television, and brokerage houses wait behind a restraining line for copies of the report. The reports are made available to all at the same time.

State and national estimates go immediately by telephone, computer, or facsimile to the State Statistical Offices where information is provided to local news media and full reports are sent to framers who request them.

Newspapers, magazines, and radio and television stations are the major disseminators of SRS data. Some information is videotaped for use by TV outlets; in other cases, slide and script summaries are mailed monthly to various TV stations. The Department also has its own weakly radio service and a spot news service (in which stations phone USDA for a short taped report) which utilize SRS report information.

The present role of the SSO's as the primary gathering and analysis organizations and the Crop Reporting Board as assimilation headquarters, the format of the statistics and reports generated, and the release and dissemination procedures are entirely adequate for the U.S. crop mission of TOSS and would continue as described above. Major differences between the USDA's activities under the U.S. crop mission of TOSS and the present system relate to the use of satellite data as the major data input for crop statistics generation and the use of a different sampling strategy for TOSS. It is these differences and analysis of their ramifications that will be the emphasis of the TOSS U.S. crop mission.

#### C.1.2 SRS STATISTICS

The Statistical Reporting Service of the USDA prepares both State and National level statistics for major U.S. crops. Released reports contain results of surveys designed to determine planted acreage (both prospective and actual plantings), harvested acreage, yield, and production during the growing season and at season's end.

##### Acreage Assessment

In general, the progression of acreage estimates is from prospective plantings to acreage intended for harvest to acreage actually harvested. Most spring-sown field crops follow this sequence: (1) acreage intended for planting as of March 1, released about mid-March; (2) acreage planted for harvest, released with the mid summer report; and (3) acreage planted and harvested, released in the Annual Crop Production Summary in January following the harvest. Fall-sown rye and winter wheat depart from this sequence, with seeded acreage estimated in December of the year preceding harvest, and winter wheat acreage for harvest in May of the next year (the growing season year).



### Prospective Plantings:

Prospective planting estimates for spring-seeded crops are based on mail surveys, with approximately 390,000 farmers receiving questionnaires regarding spring planting plans. Normally one-fourth of the questionnaires are returned, they are the basis for computing acreage indications.

Participating farmers in about two-thirds of the States receive a questionnaire asking for the number of acres planted the previous year and acreages they intend to plant in the coming season (historical/current questionnaire). Producers in the remaining States are asked to supply only current-year acreage plans. The State indications computed for each crop from the individually farm-reported data include (1) ratio to all land in farms, (2) ratio to cropland (in some western States), (3) percentage change from the previous year based on matched reports, and (4) percentage change from the previous year based on the current report of acres planted the previous year and acres intended to be planted in the current year in States using the historical/current questionnaire.

The percentage change indication, based on matched reports, is computed in all States using the current year questionnaires. The match with corresponding farm reports received from identical farmers the previous year is a major task without automated data processing systems. The task of computing the percentage change indications is simplified, however, when the historical/current questionnaires are used, because data for both years appear on the same questionnaire. One disadvantage of this type of questionnaire is that data reported by farmers for the preceding year are often subject to error

because of memory bias or other reasons. The shift from the use of the historical/ current questionnaire to the "current-year" questionnaire is being made in additional States as sampling methods and data processing capabilities permit. The change eliminates the memory bias problem and reduces respondent burden for reporting farmers.

The estimates are based on interpretations of the survey indications for each State, utilizing regression charts (see Figure C-1). The relations are plotted, using the horizontal axis for locating the magnitude of past survey indications and the vertical axis for corresponding estimates. The statistician prepares the estimate by determining the best-fit location on the graph corresponding to the current survey indication. The graph interpretation is frequently done visually, although the linear regression line is usually computed and plotted to assist interpretation. Points on the graph are identified by year so that recent year relations can be given more influence if desired.

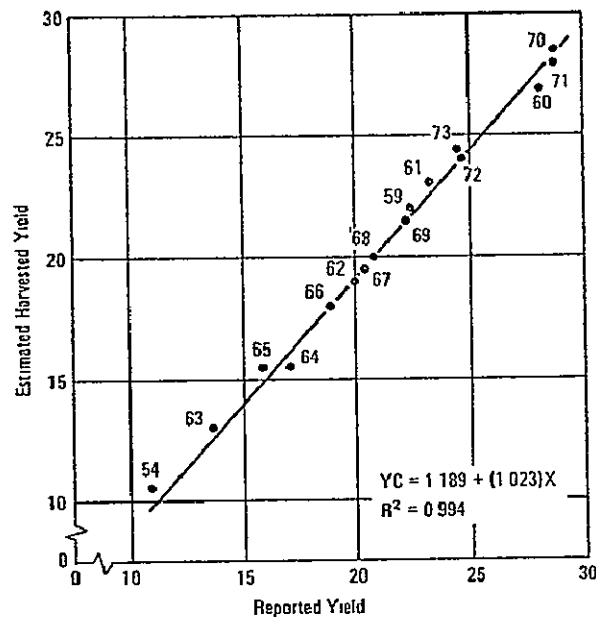


Figure C-1. Example of a regression chart used to estimate a State's winter wheat yield.

The national estimates are obtained by summing the individual State estimates. Differences between reported intended plantings and actual plantings can vary considerably, depending on changing circumstances. Changes in either economic or weather conditions can result in considerable shifts from early plans. Table C-1 shows the percentage change, 1964-1973, from the March Prospective Plantings report to the final planted acres for corn, cotton, and barley.

Table C-1. March acreage estimates for United States as percentage of final planted acreage.

Year	Corn	Cotton	Barley
1964 .....	105	100	111
1965 .....	103	101	107
1966 .....	103	105	104
1967 .....	99	106	102
1968 .....	100	102	98
1969 .....	100	101	100
1970 .....	100	102	102
1971 .....	97	98	98
1972 .....	102	97	98
1973 .....	100	105	97

Both probability enumerative and nonprobability mail surveys are conducted to establish mid-year planted acreage estimates, but only nonprobability mail surveys are carried out for the prospective planting acreage estimates. The advantage of the added precision possible with the more costly probability survey is negligible for estimating prospective plantings, because such precision would in many cases be nullified by the greater differences resulting from changes in producers' plans between survey time and actual planting.

### Midyear Acreages:

Major nationwide enumerative and mail surveys are conducted about June 1 to establish estimates of spring-planted acreages and acreages for harvest. The results are released in the July Crop Production report.

Acreage questionnaires are mailed to approximately 470,000 producers; about one-third of the questionnaires are returned and are used in computing the indications. The same kinds of indications are computed from this mail survey as for the prospective plantings surveys. Regression charts are used to evaluate the indications from the mailed surveys in setting the estimates.

The June enumerative survey includes acreage data on about 0.6 percent of the total U.S. land area. The primary indication from this survey is the direct expansion of reported acreages. Additional indications obtained from the June enumerative survey include a ratio of current year data to the previous year's data for those area segments that were enumerated both years, and a ratio-to-land indication.

The size of the area frame sample was established to obtain a relative standard error of 2 percent at the national level and about 6 percent at the State level for the direct expansion for major crop acreages. For corn, the most widely grown crop, the standard error is nearer 1 percent at the national level and less than 6 percent for major producing States. The standard errors for soybeans, winter wheat, and oats near the 2-percent, and cotton near the 3-percent, level for the Nation. The relative standard errors for minor crops exceed those for the major commodities.

The Crop Reporting Board sets the national estimates for major crops, using the June enumerative survey expansions and the mail survey ratio to land and

percentage change from the preceding year's indications. This procedure utilizes the enumerative survey expansions at their greatest level of precision. State estimates are reviewed by the Board and adjusted to add up to the national estimate.

Prior to the initiation of the enumerative survey in the mid-sixties, State estimates were established individually and added to obtain the national totals. Estimates of planted acreages and acreages for harvest for less widely grown crops are still established on an individual State basis and summed to the national total. The enumerative survey expanded data for these crops have larger relative standard errors, which limits the value of first establishing national levels. Special surveys of known growers of many of these crops supplement the general purpose surveys to provide the needed reliability at the State level.

The estimates of planted acreage published in the July Crop Production reports are normally not changed during the crop season. However, if planting is incomplete when the survey is taken in June, additional information is collected in July from a subsample of those reporting in June. A ratio indication of change from the June survey is computed and summarized at the State and national levels. Revised estimates of planted acreage are made and published in the August Crop Production report when the July survey shows that revision is needed.

Midyear estimates of harvested acreage are based on reported acres for harvest for the earliest harvested crops, such as the small grains. For the later harvested crops, such as corn and soybeans, normal allowances are made for abandonment and acres used for other purposes. The estimates of acreage for

harvest are subject to revision monthly, although they usually remain unchanged through the season. Current monthly acreage indications are obtained from the objective yield measurement program for corn, cotton, wheat, and soybeans; and for other crops from special surveys conducted when unusual weather or economic conditions occur that could result in changes in the acreage to be harvested.

#### Forecasts of Yield and Production

Forecasts of expected yield and production are issued during the growing season and estimates are issued at season's end. Forecasts and estimates are considered by SRS to be two distinct concepts. Forecasts relate to an expected future occurrence, such as crop yields expected prior to actual harvest of the crop. Estimates generally refer to an accomplished fact, such as crop yields, after the crop is harvested.

The first forecasts of yield and production are made in the December preceding harvest for winter wheat; in July for corn, flue-cured tobacco, spring and durum wheat, and other small grains; and in August for later harvested crops, such as cotton, hay, peanuts, rice, sorghum, soybeans, and sugar. Winter-wheat forecasts are made again in May and monthly thereafter through the season; forecasts for most other major crops are made monthly following the initial forecast.

The monthly forecasts are based on indications obtained from both probability and nonprobability surveys. Crop reporters provide subjective appraisals of local crop conditions and expected crop yields. General mail questionnaires are sent monthly to about 75,000 crop reporters and normally about one-third are received and summarized. In addition, to supplement the general surveys,

special questionnaires are sent to known producers of some crops which are grown in limited areas. Enumerators make objective yield counts in sample fields of approximately 3,200 corn fields, 2,500 cotton fields, 1,700 soybean fields, and 2,500 wheat fields.

The Crop Reporting Board adopts corn, cotton, soybean, and wheat forecasts for major producing States by first establishing regional levels, utilizing indications from the probability objective yield measurements and from nonprobability mail surveys. The individual State forecasts within the region are then adjusted to add up to, within rounding limits, the regional levels on the basis of the individual State indication. The forecasts of these crops for the smaller producing States are established individually, based on their respective survey indications, as are all State forecasts for crops not in the objective yield measurement program.

State yield forecasts are adopted and multiplied by the current State acreages for harvest to establish the State production forecasts. The sum of the State production forecasts is then divided by the sum of the State harvested acreages to derive the U.S. yield forecast.

A "limited-forecast" program was initiated in 1971 for most crops to conserve resources. The States of least production for each crop--those which individually account for less than 1 percent and collectively account for less than 5 percent of the U.S. production--are designated "limited-forecast" States for the crop. The initial forecast of the season is made for a crop, then carried forward unchanged in the succeeding monthly forecasts for these States. No new survey data are collected until the end-of-season surveys are made for the estimates published in the annual crop summary. This limited-forecast program was

adopted only after study indicated that the program would not significantly affect the reliability of the national forecasts.

#### Condition Reporting:

One of the original statistical activities of the Department was the reporting of condition of crops during the growing season. Later, about 1880, the concept of normal condition was initiated, with "100" used to designate normal condition. The concept is still used for the early-season forecasts when crop development has not advanced to the stage where farmers can reasonably evaluate their plantings and report expected yields.

Crop reporters are instructed to "report the condition of crops now, as compared with the normal growth and vitality you would expect at this time, if there had been no damage from unfavorable weather, insects, pests, etc. Let 100 percent represent a normal condition for field crops." The "normal" condition of a crop varies from one locality to another with differences in soil and climate. It also changes slowly in the same locality because of changes in varieties, cultural practices, and soil fertility.

#### Agromet Yield Modeling:

As the crops near maturity, crop reporters are asked to report the probable average yield in their localities. Averages of crop reporters' expectations of yield are translated into yield forecasts by means of regression charts on which final yields are plotted against reported probable for a series of years.

The objective yield data collected for corn, cotton, soybeans, and wheat include monthly plant and fruit counts.



The possibility of using weather data to forecast and estimate crop yields has been investigated on numerous occasions for most sections of the United States. The effects of weather and cultural factors are so complex that weather data alone do not provide a practical basis for estimating prospective crop yields per acre. Usually the effectiveness of rainfall is reflected in the reported condition or expected yield of a crop.

Rainfall data have, however, proved useful in estimating the winter-wheat and soybean crops especially in areas where precipitation is very influential in determining the final yield. The total rainfall during certain months has been used together with the reported condition or probable yield to reflect some measure of the ability of the crop either to respond to additional moisture or to withstand deficient rainfall. Multiple-regression equations are used, with reported condition or probable yield, rainfall during specific months, and time as separate variables in the equation, which is:

$$Y_c = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4$$

in which

$Y_c$  = computed yield per acre

$x_1$  = reported condition, or probable yield per acre

$x_2$  = precipitation for specified months prior to the date of forecast

$x_3$  = precipitation for specified months after date of forecast

$x_4$  = time

$b_1$  = multiple regression coefficients

A forecast of prospective yield or production on a given date assumes that weather conditions and damage from insects or other causes will be about normal (or the same as the average of previous years) during the remainder of the growing season. Forecasts based on current conditions and objective

counts may be appraised accurately. However, if weather, disease, insects, or other conditions change, the final estimate may differ significantly from the earlier forecast. The corn crop forecasts of 1970 and 1972 are examples of such changes. In 1970 the corn blight appeared after the August crop survey and the final U.S. corn yield was 8.5 bushels below the August forecast. An opposite situation occurred after August 1 in 1972 when nearly ideal moisture and temperature conditions improved prospects and the final U.S. corn yield was 10.5 bushels above the August 1 forecast. The difference between the August 1 forecasts and the final estimates would have been smaller in these years if more normal conditions had prevailed after August 1.

#### End-of-Year Estimates of Acreage, Yield, and Production

Estimates of acreage, yield, and production for barley, dry edible beans, oats, rice, rye, and wheat are published in the December Crop Production report and again, along with all other field crops, in the Crop Production Annual Summary the following January.

The harvested acreage, yield and production estimates are based on acreage and production (A&P) mail surveys and for wheat on final objective yield data. The mail surveys are conducted after most of the field crops have been harvested. Most States conduct two general A&P surveys, one in August or September for small grains and another in November or December for the later harvested crops. However, in a few States the crop harvest periods permit conducting only one A&P survey for all crops. Separate surveys of known producers are conducted for some crops not widely grown, or grown only in limited areas of a State, to supplement the data collected on the general surveys covering several crops.

Over 800,000 questionnaires are mailed for the A&P surveys. Farmers report acres planted and acres harvested for each major crop utilization such as grain or silage, acres abandoned or used for other purposes, and production for major utilization.

The principal indications computed from the A&P survey for harvested acres are (1) ratio to land, (2) ratio to cropland (some States), (3) percentage change from the preceding year, based on matched reports and (4) percentage of planted acres utilized for grain, silage (for some crops), and abandoned. The A&P yield indications are derived by dividing the reported production by reported acres harvested. The final yields obtained from the objective yield surveys of corn, cotton, soybeans, and wheat are based on production harvested from the sample plots by enumerators, less harvesting losses (which are determined after farmer harvest of the crop by leaning other nearby sample plots newly selected for that purpose).

Regression charts are used for interpreting the A&P mail survey indications to minimize the effect of biases that are present because of selectivity in the list and responses. The A&P survey indications and final objective yield data are the primary data sources considered in establishing the preliminary estimates. Consideration is also given to prior survey results and other available data. Supplemental information is obtained for certain crops from dealers and factories that contract acreage or production. Sugar beet factories, for instance, provide useful data on planted and harvested acreage and production.

Estimates are established on an individual State basis. The national levels of harvested acreage and production are the sum of the individual State

totals; the U.S. yield is derived by dividing the U.S. production by the U.S. acreage for harvest.

Data obtained by the Bureau of the Census from cotton ginneries provide a check of the cotton production estimate. State assessors' reports provide check data on acreage and production in some States.

#### Revised Estimates of Acreage, Yield, and Production

Estimates for all crops are subject to review and revision, if necessary, at the end of the crop marketing year. Revisions for the preceding year's crop are published for peanuts in the April Crop Production report, for cotton and tobacco in May, for sugar crops in June, and for dry edible beans, rice, and small grains in December. Revisions for all field crops are published the following January in the Crop Production Annual Summary.

The revisions, when made, are based on data that become available after the preliminary crop estimates. Such check data may include reports on cotton ginnings, soybean and flaxseed crushings, tobacco marketings, and peanut inspection. Some State assessors' reports provide check data on acreage. The preliminary estimates are viewed in the light of such check data and revised when necessary. A reevaluation of the earlier indications is performed and revisions are made in acreage and/or yield, when appropriate, to harmonize production levels with check data and original survey indications. Further review and revision are not considered until the next census of agriculture.

#### Accuracy of SRS Statistics

In regard specifically to the accuracy of SRS Statistics, the reader is again referred to Table C-1 which expresses March acreage estimates as a percentage of final planted acreage for corn, cotton, and barley. It should be noted

that such inaccuracies do not only represent errors made during the prospective acreage estimate calculation process in March; even a 100% acreage to be planted extrapolation and compilation accuracy in March would not necessarily be an entirely accurate representation of actual planted acreage because farmers do not always plant exactly the same number of acres as they indicated on the questionnaire they returned.

In a USDA/SRS publication entitled "Preparing Crop and Livestock Estimates" (March, 1974), it is stated that sampling errors for major agricultural items from the June Enumerative Survey average about 4 to 8% on a State basis, about 2 to 3% on a regional level, and about 1 to 2% for U.S. totals. As used here a sampling error of 1% means that chances are about 2 out of 3 that the sample estimate is within 1% of the result that would be obtained if the same procedure were used to survey the entire population rather than just a sample of it.

Gunnelsn et al (G. Gunnelsn, W. D. Dobson, and S. Pamperin. "Analysis of the Accuracy of USDA Crop Forecasts". American Journal of Agricultural Economics. Vol. 54, No. 4, Part 1. November, 1972. pp. 639-645) analyzed the accuracy of USDA statistics over an extended period of time, 1929 - 1970. The average absolute percentage forecast errors they calculated are summarized by crop and forecast month in Table C-2. As can easily be seen from this table, for each commodity forecasting error deminishes with each succeeding forecast revision. This suggests that procedures used by USDA to collect and incorporate additional information bearing on crop size during the growing season have been effective for increasing the accuracy of crop forecasts.

Table C-2. Average Absolute Percentage Forecasting Error\*  
in USDA Crop Forecasts by Commodity and Forecast Month, 1929-1970.\*\*

<u>Commodity</u>	<u>Dec.</u>	<u>Apr.</u>	<u>May.</u>	<u>June</u>	<u>July</u>	<u>Aug.</u>	<u>Sept.</u>	<u>Oct.</u>	<u>Nov.</u>
Winter Wheat	11.5	8.5	7.6	6.9	4.0	2.1			
Spring Wheat					10.7	6.7	3.0	2.8	
Corn					9.2	5.9	4.0	2.8	2.0
Soybeans						5.6	5.1	3.7	2.9
Oats					4.9	2.9	2.4		
Barley					7.1	3.1	2.2		
Potatoes						5.5	4.5	3.2	2.

\*The absolute difference between the forecast and the December revised estimate expressed as a percentage of the December revised estimate.

\*\*From Gunnelson et al, 1972

At closer look at Table C-2 also indicates that forecasting errors tend to be lower for commodities with shorter forecasting periods. Corn, for example, with a forecasting period extending from July to November, exhibited an initial forecasting error of 9.2% compared to 4.9% for oats with the shorter July - October forecasting period. An exception to this occurred with forecasts of spring wheat; spring wheat forecasting errors were larger than for corn which has a longer forecasting period.

Gunnelson et al. also investigated accuracy improvement of crop forecasts over existing information through the use of Theil's R statistic (Theil, Henri. Economic Forecasts and Policy. Amsterdam. North - Holland Publishing Company, 1953). The Theil R statistic or revision ratio has the advantage of not only indicating forecast accuracy, but of also identifying various types of forecast

errors. Theil's R statistic is computed by:

$$R = \frac{E_t - E_{t-1}}{A_t - E_{t-1}}$$

where

$E_t$  = current estimate

$E_{t-1}$  = previous estimate

$A_t$  = actual production

For a given comparison of  $E_t$  and  $E_{t-1}$ , if  $0 < R < 2$ , the current estimate is nearer to actual production than the previous estimate. This represents the satisfactory range of R. A perfect estimate would result in  $R = 1$ , while  $0 < R < 1$  and  $1 < R < 2$  under estimate and over estimate respectively for errors in the previous estimate. Unsatisfactory current estimates occur when  $R < 0$  and  $R > 2$ . If  $R < 0$ , a turning point error is exhibited, i.e., when  $E_t$  under estimates  $A_t$  by more  $E_{t-1}$ . When  $R > 2$ , an over compensating adjustment in the correct direction is indicated. These types of errors are considered unacceptable.

Two analyses were made: (1) Initial crop production forecasts for the year (e.g., the July corn production forecast) were compared to actual crop production for year  $t-1$  to determine whether the forecasts predicted production more accurately than the naive forecasts based on actual production for year  $t-1$ . (2) Two revised crop forecasts for each year (e.g., the August and September corn forecasts) were compared to the immediately preceding forecasts (e.g., the July and August corn forecasts) to determine whether these forecasts were more accurate than the immediately preceding ones. The resulting R statistic data is presented in Table C-3 for spring wheat, winter wheat, and an average

of seven commodities (barley, corns, oats, potatoes, soybeans, spring, and winter wheat). This table indicates that about 70% of the first forecasts were more accurate than estimates based on actual production for the previous year (see table values for 0-2) and that about 71% of the first and 72% of the second revision forecasts were more accurate than their respective previous forecasts. It should also be noted that there is a distinct tendency to underestimate, as can be readily seen when Table C-3 R statistic data is displayed graphically as in Figure C-2.

Table C-3. Distribution of R Statistics for Three Forecasts for Wheat and Seven Commodity Average (1929-1970)

FORECAST AND COMMODITY	PERCENTAGE OF R STATISTIC				
	0	0-1	1-2	2	0-2
First Forecast					
Spring Wheat	14.6	39.0	31.7	14.6	70.7
Winter Wheat	12.2	48.8	19.5	19.5	68.3
Commodity Avg.	21.6	40.5	23.5	13.9	69.9
First Revision					
Spring Wheat	21.4	61.9	7.1	9.5	69.0
Winter Wheat	35.7	57.1	2.4	4.8	59.5
Commodity Avg.	22.5	60.9	9.8	6.8	70.7
Second Revision					
Spring Wheat	14.3	64.3	11.9	9.5	76.2
Winter Wheat	35.7	42.9	9.5	11.9	52.4
Commodity Avg.	22.6	60.6	11.2	5.7	71.8



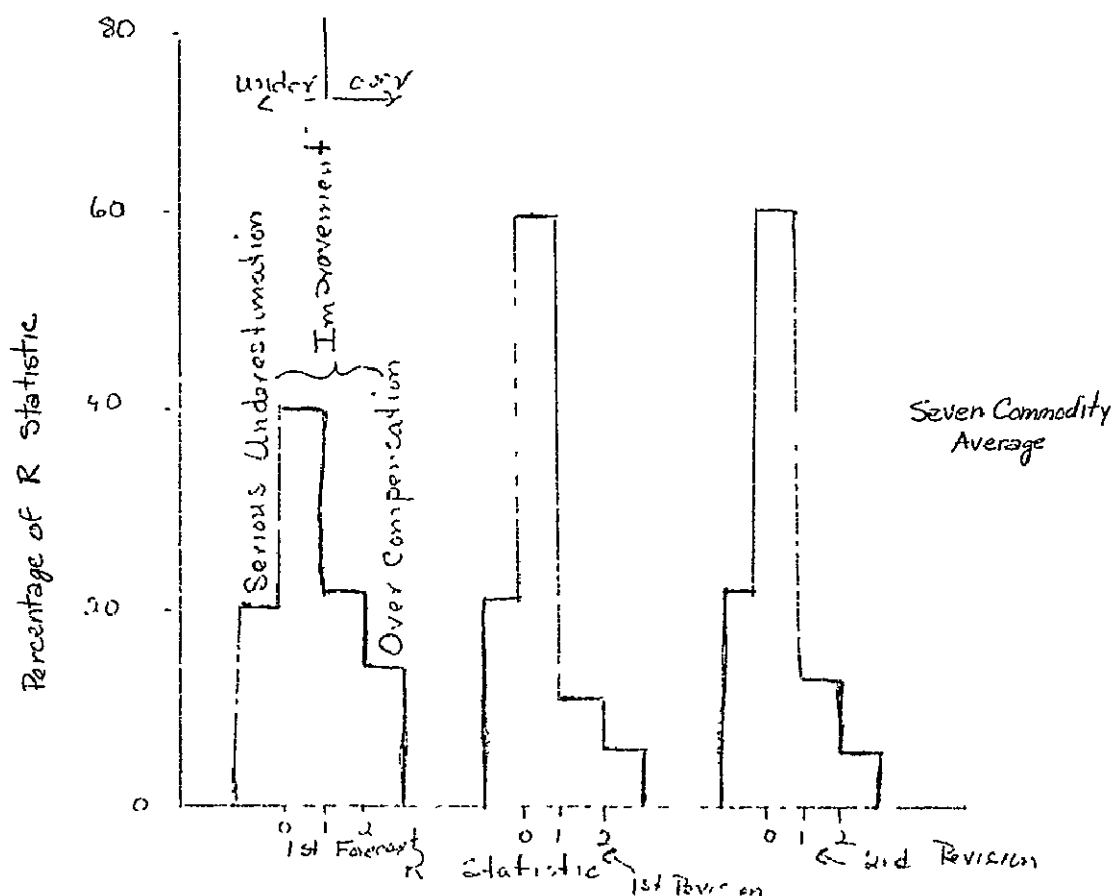


Figure C-2. U.S. R Statistic Distribution (1929-1970)

Based on these and other analysis, the following conclusions were drawn by Gunnelson et al.:

1. USDA's early production forecasts tend to underestimate crop size and the magnitude of year-to-year changes in production.
2. The USDA undercompensates for errors in earlier forecasts when developing revised crop forecasts.
3. Since 1929 the overall forecast accuracy has increased moderately.

Average production forecast errors for a shorter and more recent period, 1962-1971 were reported as part of an Earth Resources Survey cost - benefit analysis study conducted by Earth Satellite Corporation and Booz - Allen Applied Research Corporation (1974), see Table C-4. It should be noted that part of the difference between this table and Table C-2 may be attributable to the

updating (improving) of the USDA forecasting system in 1967. The author(s) point out that 1962 - 1971 average errors may be slightly high for some crops in terms of what they truly have been since 1967 but they maintain that this difference should be small because the post-1967 sample is smaller and has included anomalous years for some crops.

Table C-4. Average Production Forecast Error by Crop and Forecast, 1962 - 1971

<u>Crop</u>	<u>Apr.</u>	<u>May</u>	<u>June</u>	<u>July</u>	<u>Aug.</u>	<u>Sept.</u>	<u>Oct.</u>	<u>Nov.</u>
Winter Wheat	3.04	3.26	3.80	3.35	2.02			
Spring Wheat				6.37	6.16	2.51	2.30	
Corn				6.23	5.46	4.10	2.71	1.55
Rice				4.91	3.88	2.27	2.04	1.37
Soybeans					4.34	2.07		1.34
Oats				4.44	2.50	2.78		
Barley				4.84	1.77	1.20		
Potatoes					4.00	4.26		1.53
Cotton					6.96	5.84		2.48

R statistic analysis was also done by the Task Force on Agricultural Forecasting (D. B. Wood, Chairman, Goddard Space Flight Center, 1974) for June and August winter wheat forecasts for three crop reporting districts in Kansas to determine if local estimates were more or less consistently biased in one direction than National estimates. Data used in this analysis covered the time period 1960 - 1973. Results are shown in Table C-5 and Figure C-3. They suggest that there is less consistent propensity to underestimate at the crop reporting district level than at the National level.

Table C-5. Distribution of R Statistics for Three Kansas  
Crop Districts (1960-1973)

Forecast and District	PERCENTAGE OF R STATISTIC				C-2
	< 0	0-1	1-2	> 2	
June					
District 5	21.4	42.9	28.6	7.1	71.4
District 7	14.3	35.7	28.6	21.4	64.3
District 8	21.4	28.6	50.0	0.0	78.6
August					
District 5	14.3	28.6	35.7	21.4	64.3
District 7	7.1	50.0	35.7	7.1	85.7
District 8	28.6	28.6	42.9	0.0	71.4

Task Force calculation and summarization of forecast error, the difference between the estimate and actual production, expressed as a percentage of actual production for the 1960 - 1973 period, is shown in Figure C-4. The three curves for each district represent the mean and  $\pm 1$  sigma variance. Using as a first estimate actual production for the previous year, the forecast error is large, approximately  $\pm 22\%$  from the mean. For June the forecast error is around  $\pm 8\%$  and for August  $\pm 3\%$ . For the State of Kansas, Figure C-5, the June forecast error is  $\pm 4.8\%$  and the August error  $\pm 2.5\%$ . The error for the total U.S. estimate is approximately  $\pm 4.2\%$  for June and  $\pm 1\%$  for August. Forecast error, therefore seems to be smoothed as data is aggregated.

Finally, reference is made to conversations with SRS personnel also addressed under the topic of System Accuracy Requirements, Section C.2.2. These individuals pointed out that at present, SRS feels they can achieve National level 1 sigma variances of  $\pm 2\%$  for corn and wheat and  $\pm 3\%$  for soybeans, oats, barley, rice, and rye. State level values are  $\pm 4-5\%$  and  $\pm 5-7\%$ , respectively, for these crop groupings.

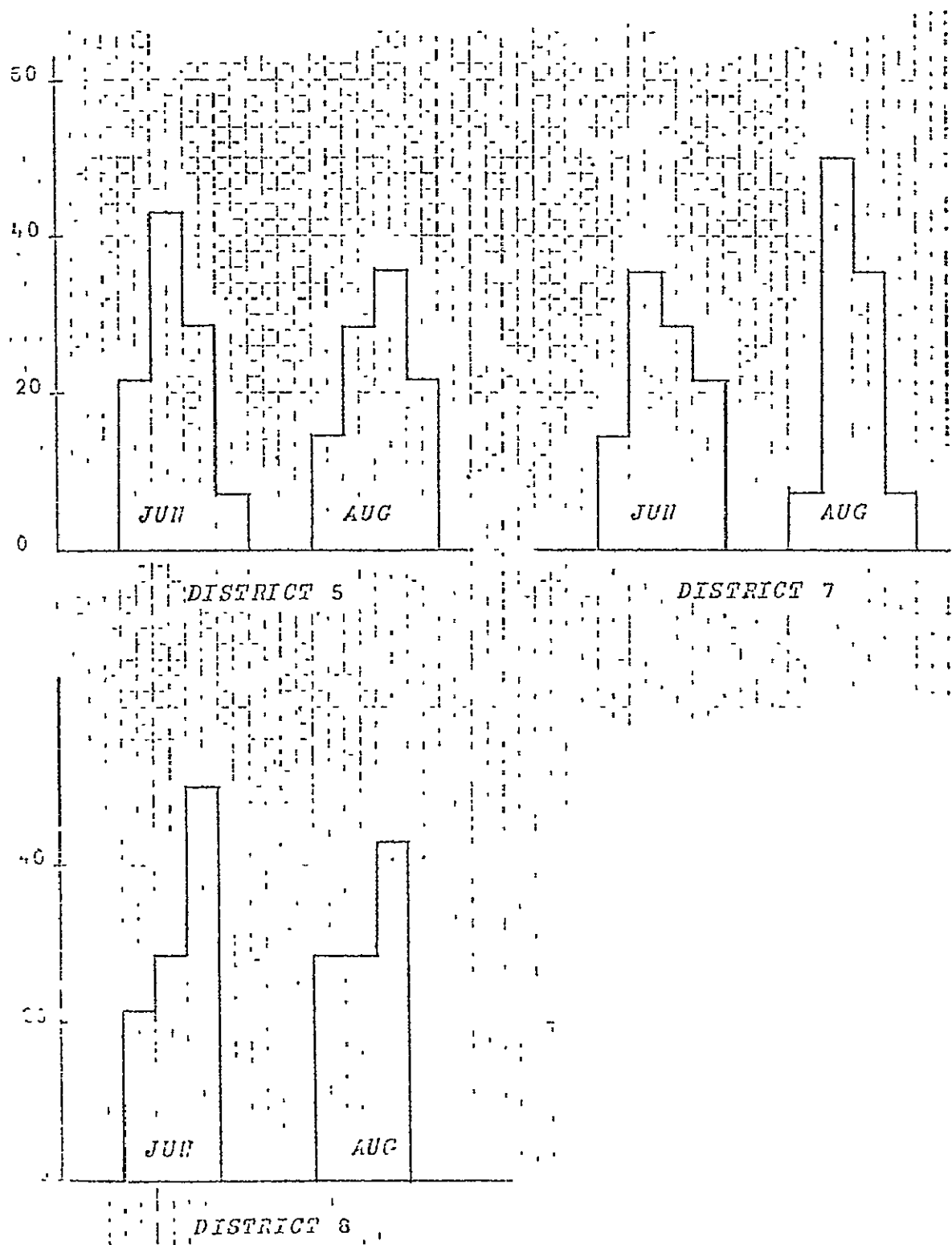


Figure C-3. R Statistic Distribution for Kansas Crop Districts

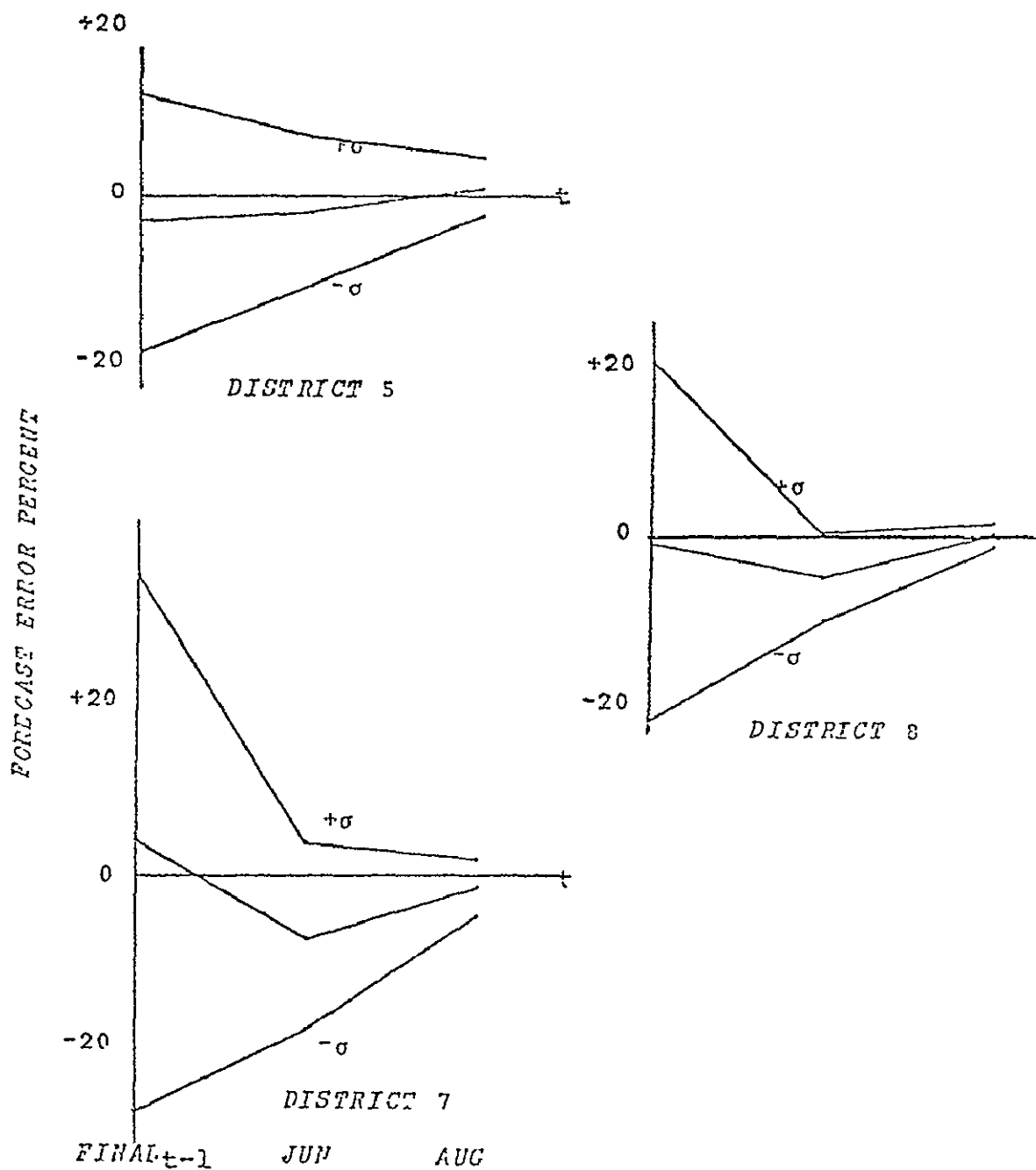


Figure C-4. Local Estimates of Winter Wheat Yield in 3 Reporting Districts in Kansas (1960-1973)

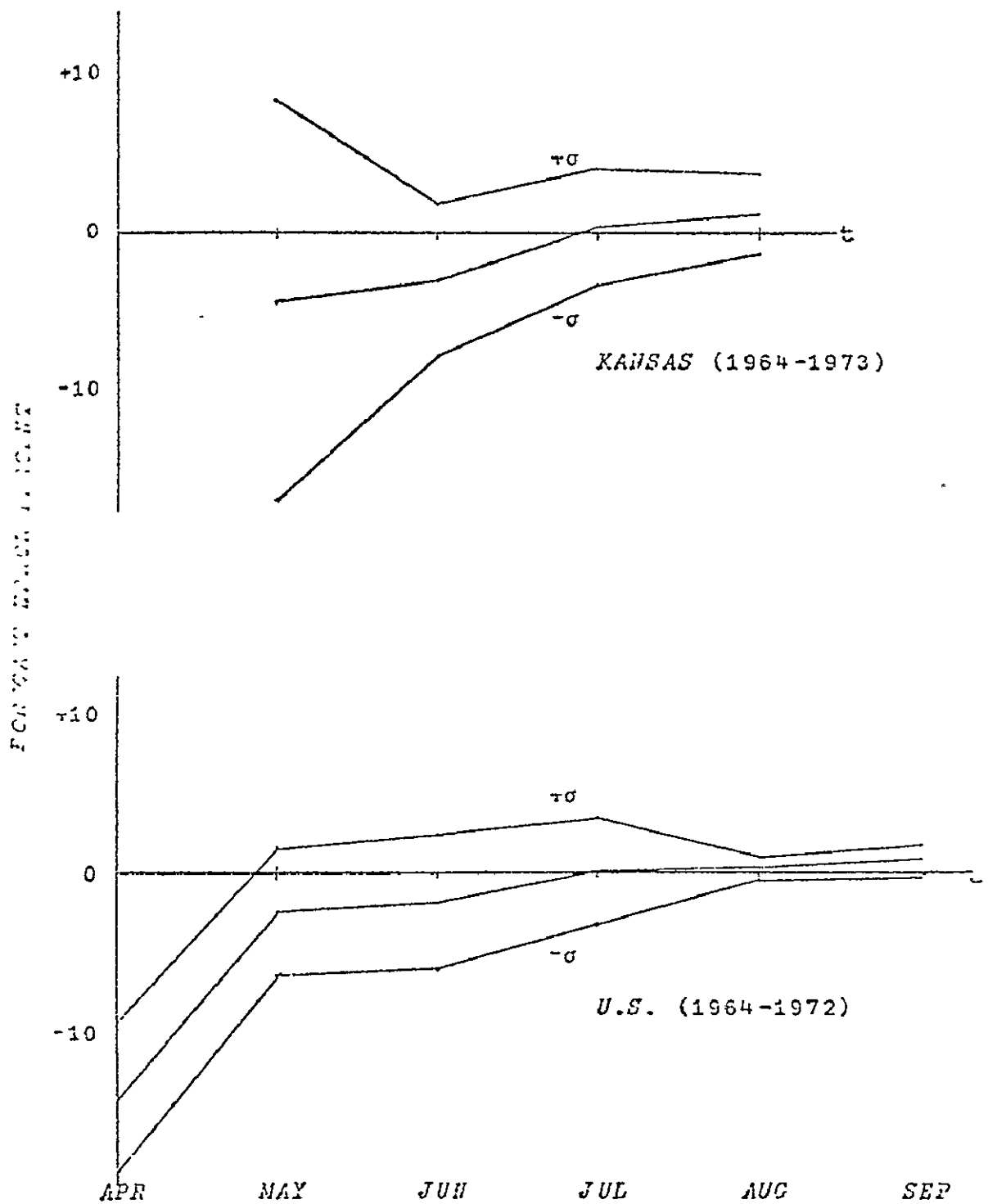


Figure C-5. Forecast Accuracy, Kansas and U.S.

## C.2 U.S. CROP MISSION REQUIREMENTS

### C.2.1 FUNCTIONAL IMPLEMENTATION CONCEPT

The functional implementation of the U.S. crop mission will involve the participation of the National Aeronautics and Space Administration (NASA), the United States Department of Agriculture (USDA), and U.S. farmers and crop inventory holders (Figure C-6).

NASA will be responsible for developing and maintaining an operational series of satellites capable of providing earth resources data to fulfill acceptable spatial, spectral, and temporal criteria. For the U.S. crop mission, adequate data must be available for derivation of monthly crop reports (except during winter months) by the USDA. Operational system data volume, timeliness, and other mission requirements necessitate that this be a "dedicated" mission and that satellite gathered data be immediately available to USDA analysts. This is achieved by direct USDA tie-in with ground stations capable of receiving the satellite sensed data.

As the data is collected by the USDA, individual sample areas are examined for data quality (cloud cover, etc.) as a means of deciding whether a computer compatible tape (CCT) is to be generated. If the decision is yes, the raw satellite data will be preprocessed to output a standard corrected CCT sample area product. With the assistance of near-real-time collected ground truth for the sample area, historical data, and other local information inputs, sample area acreage and/or yield statistics are generated for each major crop growing in the sample area. Sample area acreage and yield values are used to prepare state and U.S. production (acreage x yield) forecasts and estimates

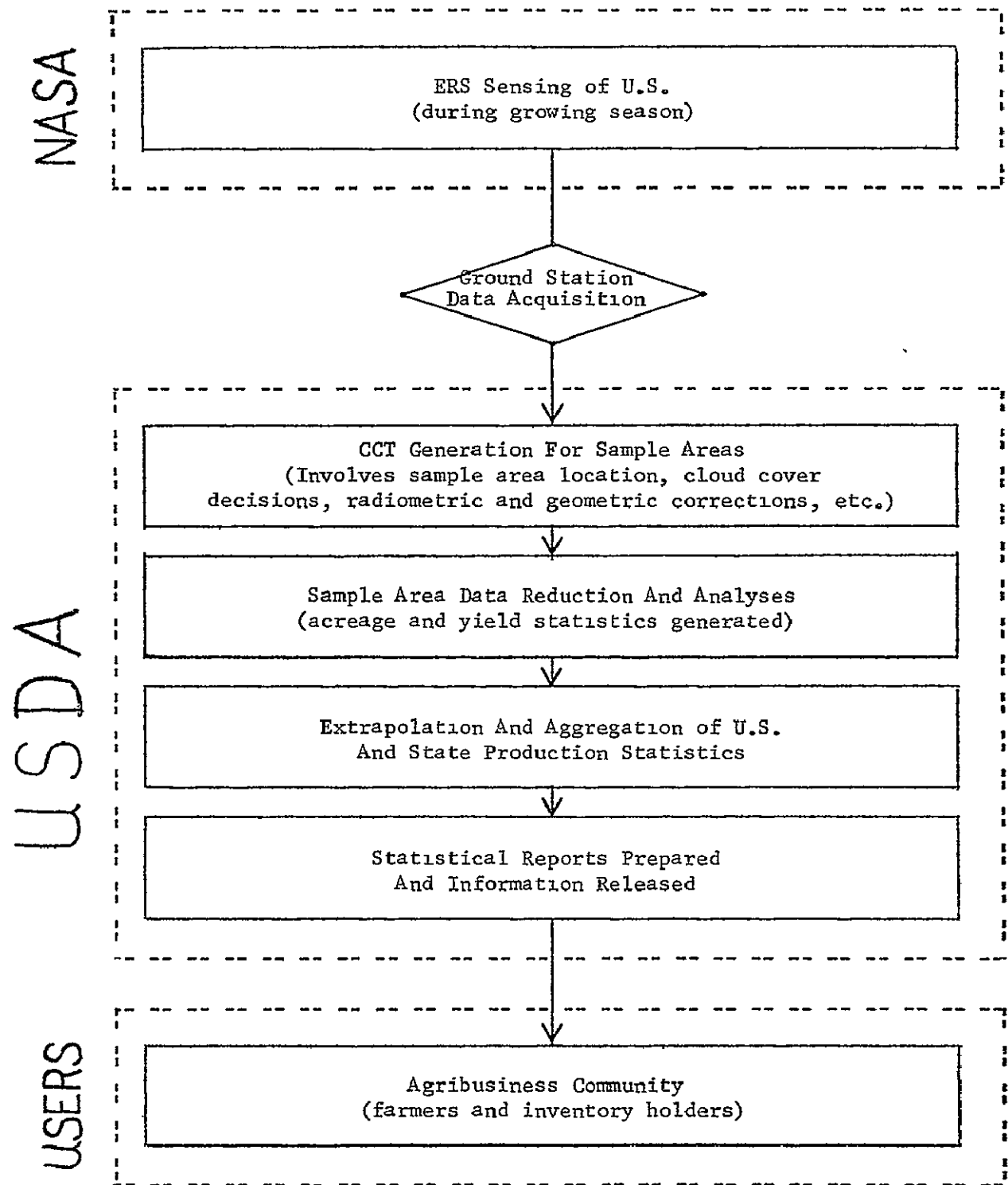


Figure C-6. Functional Implementation Concept



via extrapolation and aggregation. Statistical reports containing these U.S. and state production statistics are the final USDA output products.

Potential users of USDA gathered, assembled, and released crop production information range from the small individual farmer to large grain dealers. For example, an April report forecasting a record wheat crop might motivate a Kansas farmer to plow under some or all of his fall sown wheat crop and plant some other crop and/or might motivate a large grain dealer to sell most of its present wheat stocks by the start of this year's wheat harvest. On the other hand, a pessimistic wheat crop forecast would likely motivate the same farmer to allow his planted wheat crop to mature and the grain dealer to hold on to a significant amount of his inventory in anticipation of higher prices to come. Thus, it follows that benefits from improved crop harvest information can be realized in the short term by the making of better, financially beneficial decisions by the many varied factions of the agribusiness community. The ultimate long-term beneficiary of improved crop forecasts is the consumer, who benefits from reduced price fluctuations and reduced potential for supply surpluses and shortages.

#### C.2.2 USER INFORMATION CHARACTERIZATION

Agribusiness, ranging from the small individual farmer to Cargill, are profit motivated and need periodic, accurate, and timely crop production information if they are to make wise management and buy/sell decisions. For example, in some years as much as 30% of the fall sown wheat crop is plowed under and sown to other crops in the spring, the major individual farmer decision input being wheat crop forecasts made prior to spring planting. Wheat inventory holders involved in continuous decision making need to have some measure of how much wheat was planted in the fall, how much was plowed under in the spring,

and what harvest quantity prospects are throughout the growing season if they are to make the dollars and cents decisions most advantageous to them. Thus, there are baseline user requirements, which for the U.S. crop mission, tend to be roughly equivalent to present USDA achievements. Benefits result from a satellite data based system doing USDA's present job cheaper and/or better (that is, improved information would be obtained over what is presently obtained by USDA). It is these baseline U.S. crop mission requirements which are discussed below:

Report Cycle:

The USDA presently publishes their forecasts and estimates periodically, as shown in Figure C-7. As can be seen from this time calendar, acreage data is gathered early--planted acreage in the case of winter wheat and rye, and planting intention information for spring sown crops. Yield data is gathered prior to and during the harvest period. Yield indications, along with updated acreage information, are used to generate production figures released monthly during the middle and later portions of the growing season. It is these acreage and production statistics which are presently being used by the agribusiness community for the making of dollars and cents decisions.

Thus, it would appear that a reasonable baseline report cycle for a satellite data based system would be a "monthly" one similar to that presently employed by the USDA. Reducing the report cycle to two weeks and/or publication of production indications a month earlier would certainly be advantageous to many agricultural data users, and some sectors of the agribusiness community could even make use of as frequent as daily updates of crop production statistics.

CROP	MONTH														
	<u>D</u>	<u>J</u>	<u>F</u>	<u>M</u>	<u>A</u>	<u>M</u>	<u>J</u>	<u>J</u>	<u>A</u>	<u>S</u>	<u>O</u>	<u>N</u>	<u>D</u>	<u>J</u>	
Winter Wheat	P <sup>1</sup>					P	P	P	P	P				P <sup>4</sup>	
Rye	A <sup>1</sup>							P	P					P <sup>4</sup>	
Corn		A <sup>2</sup>		A <sup>3</sup>				P	P	P	P	P		P <sup>4</sup>	
Soybeans		A <sup>2</sup>		A <sup>3</sup>					P	P	P	P		P <sup>4</sup>	
Rice		A <sup>2</sup>		A <sup>3</sup>					P	P	P	P		P <sup>4</sup>	
Spring Wheat		A <sup>2</sup>		A <sup>3</sup>				P	P	P	P	P		P <sup>4</sup>	
Oats		A <sup>2</sup>		A <sup>3</sup>				P	P	P				P <sup>4</sup>	
Barley		A <sup>2</sup>		A <sup>3</sup>				P	P	P				P <sup>4</sup>	

<sup>1</sup> Fall planted acreage information gathered after planting. In the case of wheat yield forecast made using historical data and crop condition prior to winter and fall production forecast statistics generated.

<sup>2</sup> Early planting intention information gathered from 35 states.

<sup>3</sup> Planting intention information gathered from 48 states.

<sup>4</sup> Annual Summary which contains latest revised acreage, yield, and production figures for this year's crop plus final revised figures for last year's crop.

Figure C-7. USDA Crop Acreage (A) and Production (P) Information Publication Times for the small Grains, Corn, Soybeans, and Rice. (Note: When production figures are released, acreage and yield values are also published.)

### System Accuracy:

Regardless of how often crop forecasts and estimates are published, the user community will respond to the statistics in one manner or another. A response will take place regardless of the accuracy or inaccuracy of the information; however, when the published figures are highly accurate, the benefits derived from the information will be greater because a higher percentage of the data users will make correct (higher profit generating) decisions. Thus, a baseline accuracy goal needs to be set and again the achievements and goals of the USDA/SRS will significantly influence the system accuracy value selected for the U.S. crop mission.

In a study analyzing the accuracy of USDA forecasts over the 1929 - 1970 period, Gunnelson et al. (American Journal of Agricultural Economics, Vol 54, Nov. 1972, pp 639-645) reported average final forecast errors ranging from 2.0 to 2.9 for National level forecasts of several major U.S. crops (see Table C-6). Study results also suggested a trend toward moderate improvement in accuracy during the more recent years of this period.

William Kibler, Director, Survey Division of SRS, in an October 11, 1974 letter to Edward Risley, Executive Secretary, Requirements and Benefits Subcommittee, ICC ERSP, points out that in 1967 SRS finalized a new operational program of probability surveys for use in the 48 conterminous states. This survey program was designed to improve the accuracy of the crop reports issued at regular intervals and fulfilled its objectives effectively.

TABLE C-6.- SIZE OF AVERAGE ABSOLUTE PERCENTAGE ERROR OF  
USDA CROP FORECASTS, 1929 - 1970

<u>Crop</u>	<u>Forecasting Error*</u>
Corn	2.0
Winter Wheat	2.1
Barley	2.2
Oats	2.4
Spring Wheat	2.8
Soybeans	2.9

\*Forecasting error equals the absolute difference between the last monthly forecast and the December revised estimate (published in the Annual Summary) expressed as a percentage of the December revised estimate.

According to Scope and Methods of the Statistical Reporting Service (USDA/ SRS Miscellaneous Publication No. 1308; July, 1975), SRS sampling strategy is designed so as to obtain a relative standard error of 2% at the national level and about 6% at the state level for the direct expansion for major crop acreages. For corn, the most widely grown crop, the standard error is nearer 1% at the national level and less than 6% for major producing states. The standard errors for soybeans, winter wheat, and oats are near 2% for the nation. For other crops, relative standard errors are indicated as exceeding the values for these major commodities.

Conversations with several SRS personnel have led to the conclusion that both acreage and production goals are for achievement of 98% accuracy for corn and wheat, and 97-98% for soybeans, oats, barley, rice, and rye. On the state

level, goals range from 4-5% error for corn and wheat to 5-7% error for barley, oats, soybeans, rice, and rye in states where more than 2% of the land area of the state is devoted to that crop.

Thus, it would appear that 98% accuracy, 95% of the time would be a realistic general national level baseline system accuracy goal for the U.S. crop mission. This would assure that results achieved via the satellite system were at least as good as SRS obtains now. State level goals should be 95% accuracy, 95% of the time.

#### Staleness of Data:

Regardless of how accurately ever-changing parameters are measured at any point in time, greater inaccuracy results each day after measurement. Since production, affected by changes both in acreage and yield (each of which is constantly changing), is an extremely dynamic variable, operational crop production forecasting systems need to publish "fresh" data if they are to be highly accurate at time of report release. "Staleness of Data" as used herein then will refer to the time from when the oldest piece of data used in a report was collected to the time when the assembled statistics are released.

The 1974 release dates of Crop Production, the official USDA publication containing crop acreage, yield, and production forecasts and estimates, for May through November ranged from the 8th to the 12th of the month (see Table C-7). Law (Title 7, Section 411a) requires that release be no later than the 12th of the month. Since data is normally gathered the last week of the previous month and the first week of the month during which it is released (for example, June 19th released data would have been gathered the last week of May and the first week of June) the earliest collected data has a staleness of

approximately 14 to 18 days. Thus, for equivalent staleness of data achievement, the satellite has to sense a sufficient number of cloud-free sample areas and data from these sample areas has to be analyzed, assembled, and released within approximately a 16 day period. It should be noted that 16 days is about half a month and that a 15 to 16 day data staleness interval would allow for the publication of production statistics twice a month.

TABLE C-7.- 1974 RELEASE DATES OF MAY - NOVEMBER ISSUES  
OF CROP PRODUCTION

<u>Month</u>	<u>Issue Day</u>
May	8th
June	10th
July	11th
August	12th
September	11th
October	10th
November	8th

Output Product:

The output product of the U.S. crop mission would be the same as that presently released by the USDA: Current crop acreage and production forecasts and estimates via statistical report publication. The format would be the same as that presently followed in Crop Production (see attached Appendix for an example of the output format and content of a monthly issue of Crop Production). This output product and format has proven understandable and useful to the agribusiness and agricultural data user community in the past and there is certainly no reason that it be changed with the incorporation of satellite data into the the USDA's data gathering procedure.

### Output Distribution:

U.S. and state-level official crop statistics preparation, release, and distribution would follow a procedure which for the most part would be analogous to that being used by the USDA today. Highlights of this procedure are discussed below.

In December each year, the date and hour of the release of each SRS - Washington, D.C. report for the coming year is announced (see attached Appendix for 1974 announcement). With few exceptions, reports are issued at the specified time. The State Statistical Offices make the national and state information available immediately after the Washington release.

Estimates of production of corn, wheat, cotton, soybeans, and sweet oranges, and the supply of grain in storage are defined as "speculative." These commodities are heavily traded on commodity markets and anyone having access to official estimates would have an obvious advantage in trading. Precautions are taken to prevent unauthorized access to such information before its official release. Reports from surveys on the speculative commodities from the major producing states go through the mails in distinctive envelopes and receive special handling. When they arrive at USDA in Washington, they are placed in a special steel box secured by two locks. One key is held by the Office of the Secretary of Agriculture and the other by the Secretary of the Crop Reporting Board.

Early on the morning of crop report day, the Chairman and a representative of the Secretary, escorted by a USDA guard, open the box, remove the reports, and take them to the Board rooms.



While the reports are being prepared, the area is isolated and guarded. Doors are locked, the window blinds closed and sealed, and all telephones disconnected. Food is sent in. Only authorized persons may enter, and no one leaves until the report is released.

Commodity indications from the State Statistical Offices are reviewed by the specialists in the Estimates Division and those serving on the Crop Reporting Board to arrive at official State estimates and a national total.

Strict security precautions are also imposed for reports designated as "non-speculative." Although not prepared behind locked doors, material for these reports is worked on in restricted areas and access by unauthorized persons is denied. These estimates, too, are reviewed by the Crop Reporting Board before release.

The law specifies statutory penalties that can be imposed upon SRS employees for disclosing any data or crop information prior to official release, or personally engaging in trading on the commodity markets. The penalty can be a \$10,000 fine and 10 years in prison. Issuing false information may bring a \$5,000 fine and 5 years in prison.

Shortly before the lockup report is to be released, the Secretary of Agriculture or his representative enters the Board room for his first look at the commodity estimates, and receives a briefing on the report, which has been printed inside the lockup. He then signs the report.

Minutes prior to release time, the Chairman, Secretary, and a limited number of Board members take copies of the report to the newsroom outside the locked area. No communication with anyone is permitted. Reporters from wire services,

newspapers, radio, television, and brokerage houses wait behind a restraining line for copies of the report. The reports are made available to all at the same time.

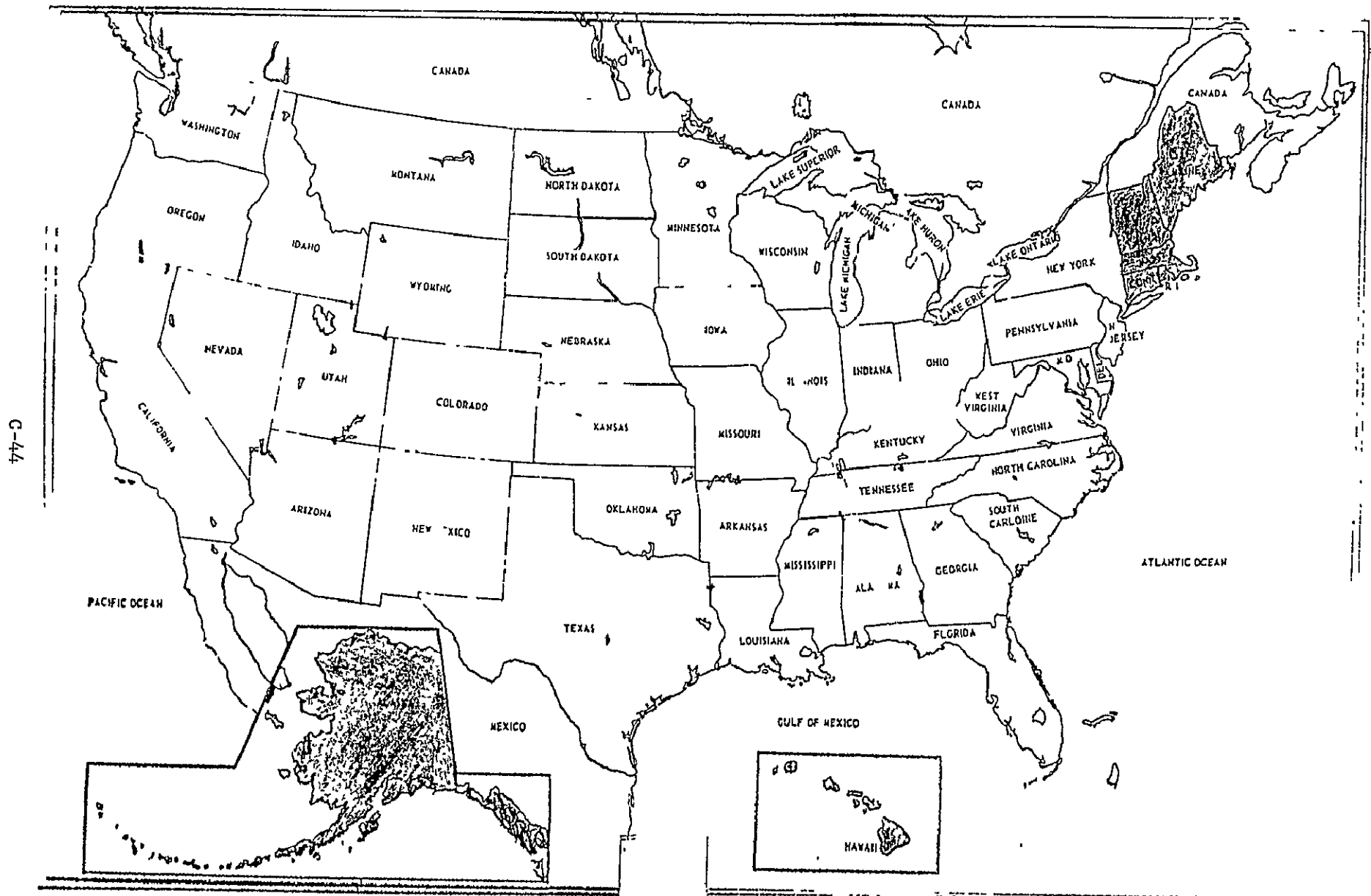
State and national estimates go immediately by telephone, computer, or facsimile to the State Statistical Offices where information is provided to local news media and full reports are sent to farmers who request them.

In the case of U.S. crop statistics generation using satellite data inputs, the detailed data extraction (acreage by crop, etc.) should also be carried out at the State Statistical Offices if feasible in terms of data relay to these offices. This decentralized approach has proven to be quite successful because statisticians located in the State Statistical Offices can best adapt general procedures to varied local circumstances and have a better grasp of regional conditions affecting agriculture. It is believed that regional or national-level satellite data analysis centralization could have a significant negative impact upon the accuracy of the final compiled statistics.

#### Area of Coverage:

The U.S. crop mission area of coverage will encompass the States of the U.S. which are significant producers of at least one of the seven crops being addressed in this study: wheat (winter and spring), soybeans, corn, rice, oats, barley, and rye. Although not an absolute definition, a significant producer can be considered to be a state which contains more than 1% of the total U.S. acreage of one of these crops. In total, this will involve collecting data in approximately 42 states, excluded states being Hawaii, Alaska, and several New England states (see Figure C-8). In the covered states, statistics will need to be generated for each crop for which that state is a significant producer.

Figure C-8. Area of Coverage for U.S. Crop Mission\*



\* States to be covered in white, states in green not significant producers of wheat, soybeans, corn, rice, oats, barley, or rye.

#### Information Grid Size:

As indicated above, the basic information compilation grid size is the State, of which about 42 will be sensed. Several strata are outlined within each of the states based on cropping density and individual sample areas are randomly selected from within these strata.

#### C.3 INFORMATION FLOW - U.S. CROP MISSION

The U.S. crop mission information flow incorporates the functions of three groups: (1) NASA - launches and maintains satellites capable of providing timely earth resources data, (2) U.S.D.A. - interprets and analyses satellite and other gathered real time and historical data to prepare periodic State and U.S. level crop acreage, yield, production, etc. statistics, and (3) applications community - makes management, buy/sell, etc. decisions. Highlights of the information flow are diagrammed in Figure C-9 and discussed below.

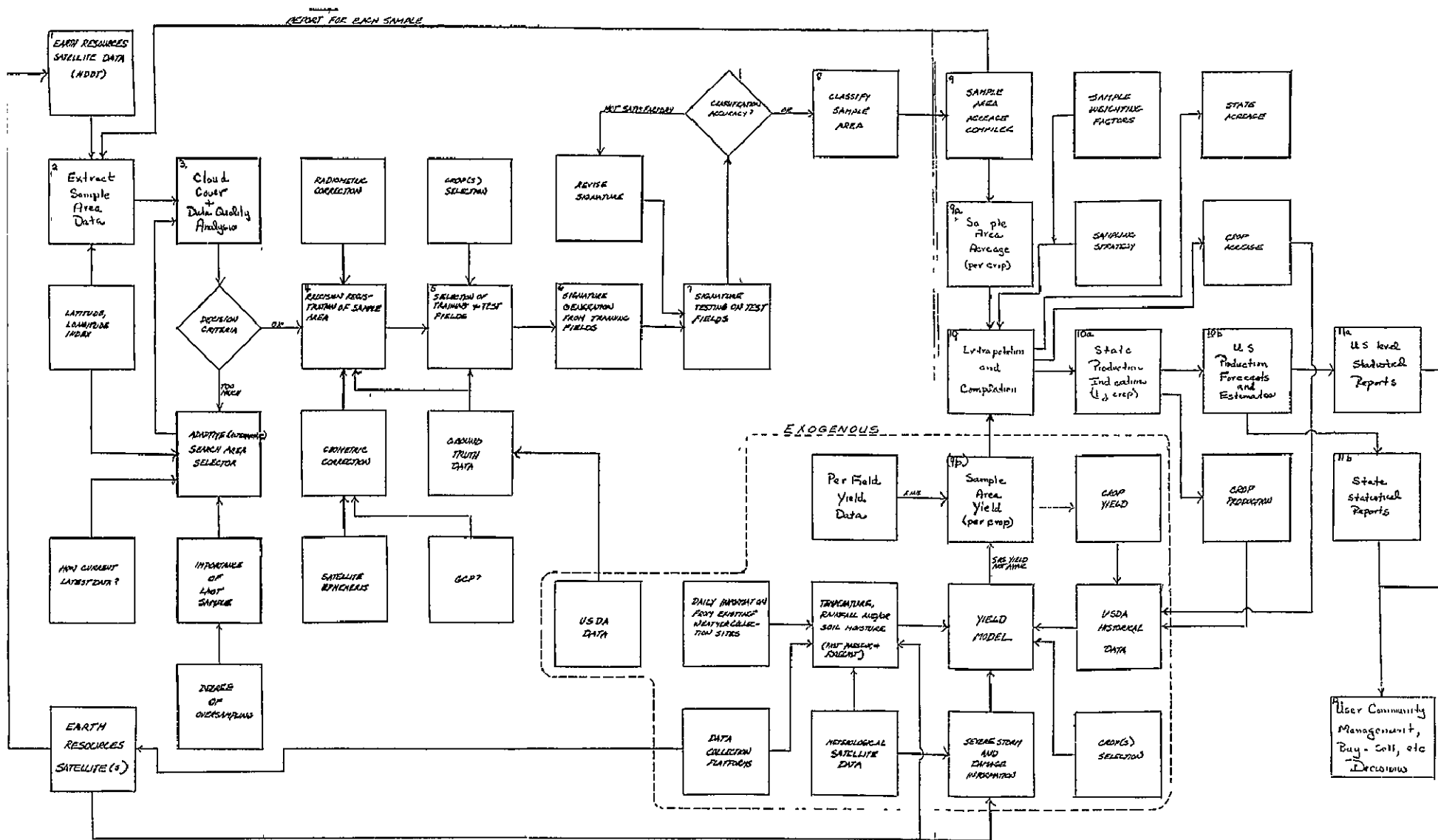
#### Earth Resources Satellite Data

Data from repetitive coverage of the U.S. during the growing season (from April through Nov. for certain sections of the country) will be needed. The raw data will be transmitted in real time to ground receiving stations so as to be available to U.S.D.A. analysts immediately after sensing.

#### Sample Area Data Extraction

From the total area survey data, individual sample areas will be located. It is these sample areas which will be studied in detail, results being extrapolated and compiled to produce large area crop statistics. Thus, generated CCT's will be of sample areas only, not of entire imagery frames.

Figure C-9 Information Flow U.S. Crop Mission



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#### Cloud Cover & Data Quality Analysis

Sample area CCT's will be generated if cloud cover and data quality requirements are met. Decision analyses could be performed automatically or interactively. For example, in the case of less than good data quality, a decision to apply a data correction procedure might be made, especially if data for that sample area was not suitable for the previous overpass or two. In general, cloud cover acceptability would probably require zero cloud cover over the sample area but under certain conditions this decision guideline might also be modified.

#### Sample Area Data Correction and Registration

For suitable sample areas, standardized CCT's will be generated. Data will be organized into a standard format and geometrically and radiometrically corrected and calibrated. The sample area will also be registered with a previous analysis of the same area. This will allow for change detection analysis, eliminate the need for training and test field selection and location each time a sample area is analyzed, and improve crop classification accuracy and/or make it possible to obtain a particular accuracy at an earlier time during the growing season.

#### Crop Signature Development and Refinement

For the crop(s) of interest for a particular sample area, required ground truth will include crop identification, acreage, and phenology and general crop condition information on fields located throughout the sample area to be used for training and testing. Initial crop signatures will be obtained using fields designated for training and crop acreage classification accuracies determined using the test field group. Required signature modifications will be made until suitable test field crop acreage accuracies are

obtained. It is these crop signatures that will be used to classify the entire sample area.

#### Sample Area Crop Acreage

Sample area classification using the refined signature of each crop of interest grown within that sample area will yield sample area crop acreage figures.

It is these statistics which represent, for the most part, the basic satellite data measured crop information. Larger area acreage statistics are obtained via extrapolation and compilation of individual sample area crop acreage figures, and yield will not be measured directly using satellite imagery as the major data source.

#### Sample Area Crop Yield

Although it will not be directly measured using satellite data, as was the case with acreage, some local level (sample area) assessment of crop yield will also be required if production is to be calculated. The source of this yield information would be periodic objective yield surveys or yield model generated values using historical yield and gathered yield modifying information as input.

#### Calculation, Extrapolation, and Compilation of State and U.S. Crop Production Statistics

At the sample area level, crop production is merely the multiplication of measured crop acreage times the yield value acquired. However, since complete surveying is not done, the sampling strategy used to select sample areas and sample weighting factors need to be considered when preparing larger area, such as State and U.S. level, production figures.

In general, highlights of the State and U.S. level statistics preparation procedure include the following: The State Statistical Offices edit, summarize, analyze, and expand sample area acreage and yield data into State production "indications". These initial forecasts or estimates are then forwarded to Washington for review by the Crop Reporting Board. An explanation of survey methods and unusual conditions affecting a forecaster estimate, along with any other supporting data and pertinent information, are included in the attached commentary.

Upon their receipt in Washington, the State data are summarized nationally for each item. For many commodities, a national estimate is made first in order to make use of check data and other information that are available at the national level. The Board members review the various data and establish official State & National level forecasts and estimates.

#### U.S. and State Statistical Reports

According to a published release schedule, official State and national level forecasts and estimates, along with interpretive comments, are issued from Washington and from the SRS field offices. Full reports are mailed to individuals who request them and summaries are communicated to local news media immediately by telephone, computer, or facsimile. An example of a U.S. level report is presented in an attached Appendix . An example of State level information as it is presently being prepared by State Statistical Offices (the example being for Iowa) is also included as an Appendix.

#### Application by Agricultural Data User Community

Published crop statistics are used throughout the agribusiness community as inputs into management, buy-sell, etc. decisions (see section 1.0). Indeed,



it is the benefits achieved by the American economy and the American consumer from the application of agricultural information which provides the justification for the gathering of crop statistics in the first place.

## SUB APPENDICES

The following material is included as sub appendices to provide further information and examples.

- o USDA Regulations Governing Crop Reports
- o Laws Governing Crop Reports
- o July 1974 "Crop Production"
- o Crop Reporting Board Reports - 1974 Issuance Dates and Contents
- o Iowa Crop and Livestock Reporting Service, "Corn Acreage and Production"

# USDA Regulations Governing Crop Reports

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The official regulations of the Department of Agriculture concerning the preparation of the agricultural data estimates of the Service follow:

## Title 1—General Authorities and Functions

### Chapter 6—Other Authorities and Functions

#### Section 1—Crop Reporting Board

#### 325 AUTHORITIES AND FUNCTIONS (S)—

There shall be in the Statistical Reporting Service a Crop Reporting Board, the primary function of which shall be to prepare and issue, as provided in paragraph 328 and elsewhere in this regulation, the official State and National estimates and reports of the Department relating to crop production, livestock and livestock products, numbers of livestock on farms, stocks of agricultural commodities, local market prices, value of farm products, and such other subjects as the Administrator of the Statistical Reporting Service may direct. Among these reports shall be a Monthly Crop Report, which shall be issued on or before the 12th of each month pursuant to 7 U.S.C. 411a, a Cotton Acreage Report to be issued on or before the 10th of July, and the Cotton Crop Report to be issued on the 8th day of each month from August to December, or, if the 8th day is a nonwork day, on the next succeeding workday, pursuant to 7 U.S.C. 475 and 476.

326 DEFINITIONS —As used in these regulations, "Department" means the United States Department of Agriculture, "Service" means the Statistical Reporting Service staff engaged in statistical reporting work, and "Board" means the Crop Reporting Board.

327 ORGANIZATION OF BOARD *a. Chairman* —The Deputy Administrator of the Statistical Reporting Service is the Chairman of the Board. He shall call and preside over all meetings of the Board. As Deputy Administrator of the Statistical Reporting Service, he shall issue the necessary instructions for gathering, compiling, and summarizing data for reports specified

in paragraph 328, and shall approve the statistical techniques and procedures to be followed by the Service and by the Board in analyzing, interpreting, and reviewing the pertinent data and in preparing the official estimates for each report.

*b. Members* —The Chairman shall select the members of the Board for each report from the Service. The Board, for the Monthly Crop Report, shall have not less than five members in addition to the Chairman, and except for February, March and December, not less than two of them shall be selected from the Service field offices. For the Cotton Report the Board shall have not less than five members in addition to the Chairman, of whom not less than three members shall be supervisory field statisticians located in different sections of the cotton growing States, experienced in estimating cotton production and who have first-hand knowledge of the condition of the cotton crop based on recent field observations, and a majority of the Board shall be familiar with the methods and practices of producing cotton, as provided in the Act of May 3, 1924, as amended (7 U.S.C. 475). For the Annual Crop Production Summary in December, the Winter Wheat and Rye Report as of December 1, the Prospective Plantings Report as of March 1, the Annual Livestock Summary as of January 1, and the Pig Crop Reports as of June 1 and December 1, the Board shall consist of not less than five members, in addition to the Chairman, of whom not less than two shall be selected from the Service field offices.

*c. Secretary of the Board* —The Board shall have a permanent Secretary, who shall be a professional member of the Service in Washington. He shall assist in preparing instructions and forms for collecting, compiling, summarizing, and analyzing statistical information for the use of the Board, shall arrange for suitable means for transmission of instructions, records, and reports to and from the field offices, shall maintain records of the information assembled, including a record

of the official estimates prepared by the Board, and shall maintain a file of the signed copies of Board reports. For each report the Secretary shall assemble and collate information for the use of the Board, issue proper notices of Board meetings, and make necessary arrangements for the preparation, signing, and release of reports in such manner and at such times as are herein described.

328 *REPORTS a Reports to be approved by the Secretary of Agriculture*—The following Board reports shall be signed by the Chairman, Secretary, and members of the Board, and shall be approved by the Secretary of Agriculture before being issued or published:

- Monthly Crop Reports (see paragraph 325)
- Cotton Reports (see paragraph 325)
- Annual Crop Production Summary in December
- Winter Wheat and Rye Report as of December 1
- Prospective Plantings Report as of March 1.
- Annual Livestock Summary as of January 1.
- Pig Crop Reports as of June 1 and December 1.

b *Other Board reports*—Such other reports as are designated by the Chairman shall be prepared and issued as Board reports. For each such report, the Chairman shall select Board members from the Service in such manner and in such numbers as may be deemed necessary. Such reports shall be approved by the Chairman or his designee before being issued.

c *Annual release schedule*.—On or before the first day of December of each year there shall be prepared a schedule for the ensuing year setting forth dates and hours of release of all regular statistical reports listed in subparagraph "a" above for which the approval of the Secretary of Agriculture is required. The schedule of reports shall be effective when approved by the Secretary of Agriculture and may be amended at any time with his approval. Subsequently, there shall also be prepared and issued, to the extent possible, an advance listing of the reports referred to in subparagraph "b" above, together with dates of publication or issuance.

329 *COLLECTION OF INFORMATION* — For use in preparing the official estimates of the Department, information relating to agriculture shall be gathered through the Washington and field

offices of the Service, as far as practicable, from practical farmers, as provided in 7 U.S.C. 411a, from peanut processors, as provided in 7 U.S.C. 951 et seq., from processors, dealers, cooperating State and local officials, agencies in the Department, and from other sources. This information shall be collected by mailed questionnaire, by sample enumeration, by interviews, or by other appropriate means (7 U.S.C. 411a, 951).

330 *INFORMATION NOT TO BE RELEASED; SPECULATION; FALSE STATISTICS*

a *Withholding information*—The contents and every part of the contents of each and every report specified in paragraph 328a, and the information and every part of the information utilized in the preparation of such reports, shall be withheld from publication until the day and hour provided for the issuance of the reports in the schedule approved by the Secretary of Agriculture and amendments thereto.

b *Access to information*.—No member of the Board or other persons engaged in the preparation of information for reports, shall, before the release of any Board report provided for herein, willfully impart or permit access to any information contained therein or any part thereof, directly or indirectly, to any person not entitled under the law and rules of the Department to receive the same. The Chairman may under this regulation notify officers in charge of field offices, in advance of publication, of changes made by the Board from recommendations submitted by such officers for nonspeculative items as defined in paragraph 331a(2).

c *Statutory provisions*

(1) "Whoever, being an officer, employee or person acting for or on behalf of the United States or any department or agency thereof, and having by virtue of his office, employment or position, become possessed of information which might influence or affect the market value of any product of the soil grown within the United States, which information is by law or by the rules of such department or agency required to be withheld from publication until a fixed time, willfully imparts, directly or indirectly, such information, or any part thereof, to any person not entitled under the law or the rules of the department or agency to receive the same; or, before such information is made public through

## USDA REGULATIONS GOVERNING CROP REPORTS

regular official channels, directly or indirectly speculates in any such product by buying or selling the same in any quantity, shall be fined not more than \$10,000 or imprisoned not more than ten years, or both "

No person shall be deemed guilty of a violation of any such rules, unless prior to such alleged violation he shall have had actual knowledge thereof " (June 25, 1948, ch 645, sec 1, 62 Stat 790, 18 U S C 1902 )

(2) "Whoever, being an officer or employee of the United States or any of its agencies, whose duties require the compilation or report of statistics or information relating to the products of the soil, knowingly compiles for issuance, or issues, any false statistics or information as a report of the United States or any of its agencies, shall be fined not more than \$5,000 or imprisoned not more than 5 years, or both " (June 25, 1948, ch. 645, sec 1, 62 Stat 795, 18 U S C 2072.)

331 SPECULATIVE AND NONSPECULATIVE DATA a *Definition*—Data used by the Board in the preparation of the Monthly Crop Report and the Cotton Report shall be classified as follows.

(1) *Speculative data*—Speculative data are defined to be data relating to corn, wheat, oats, cotton, soybeans, or sweet oranges, the assembling and collating of which would make it possible for any member, members, or assistants of the Board approximately to anticipate the Board's forthcoming report for the United States on the condition, yield, probable production, or farm stocks of designated commodities, or the acreage or ginnings of cotton. These data shall be deemed to be speculative for.

(a) *Corn* in Illinois, Indiana, Iowa, Minnesota, Missouri, Nebraska, and Ohio

(b) *Winter wheat* in Illinois, Indiana, Kansas, Missouri, Nebraska, Ohio, Oklahoma, and Texas

(c) *Spring wheat* in Minnesota, Montana, North Dakota and South Dakota

(d) *Oats* in Illinois, Iowa, Minnesota, North Dakota, South Dakota, and Wisconsin

(e) *Cotton* in Arkansas, Louisiana, Mississippi, and Texas

(f) *Soybeans* in Arkansas, Illinois, Indiana, Iowa, Mississippi, Missouri, Minnesota, and Ohio

(g) *Sweet oranges* in California and Florida.

(2) *Nonspeculative data*.—Nonspeculative data are defined to be any statistical data other than the speculative data defined in paragraph (1) above

b *Transmission*

(1) *Field procedure*—Summaries of speculative data collected in the field offices, together with recommendations of the officer in charge of each such office, shall be transmitted by mail or telegraph to the Secretary of Agriculture. When transmitted by mail, the summaries and recommendations shall be forwarded in a sealed envelope marked "Special A." When transmitted by telegraph, the summary and recommendations shall be forwarded in a secret code provided by the Secretary of the Board. Nonspeculative data may at all times be forwarded directly to the Secretary of the Board by the officers in charge of the field offices

(2) *Departmental procedure*—Immediately upon its receipt in the Department Telegraph Office, each telegram containing speculative crop report data shall be placed in a sealed envelope marked "Special A" in the Department Telegraph Office and delivered by special messenger to the Office of the Secretary of Agriculture

c *Custody of "Special A" envelopes*—All "Special A" envelopes containing speculative crop report data received in the Office of the Secretary of Agriculture shall, immediately upon receipt and without breaking the seals thereof, be placed in the locked box provided for that purpose in the Office of the Secretary of Agriculture.

d *Opening of "Special A" envelopes*.—Immediately preceding the convening of the Board on the day a report is to be published, the locked box in the Office of the Secretary of Agriculture containing the "Special A" envelopes shall be opened and the envelopes removed in the presence of a designated representative of the Secretary of Agriculture, the Chairman, Secretary, and one other member of the Board, and a special guard provided by the General Services Administration. The Chairman, Secretary, and other member of the Board, accompanied by the guard, shall then proceed directly to the Board rooms.

332 BOARD ROOMS. a *Definition*—The Board rooms shall consist of the Board room proper and all other rooms occupied during the

locked-in session of the Board by clerks, stenographers, and others engaged in assisting the Board in the preparation of the report

b *Safeguards against communication of information*—Previous to the arrival of the Board representatives and guard with the sealed "Special A" envelopes, the Secretary of the Board shall have caused all windows in the Board rooms to be sealed in such manner as to prevent communication between persons within the Board rooms and persons outside. Also, previous to the arrival, all telephones in the Board rooms and connected with the central Department telephone switchboard shall be disconnected at the central switchboard, and any other means of communication from the Board rooms shall be similarly disconnected. Immediately after the entrance of the Board representatives into the Board rooms, with the sealed "Special A" envelopes, the guard shall lock all doors leading from the Board rooms, and remain on watch until the report is released. While on watch, the guard shall not permit any communication between persons within the Board rooms and persons outside except as provided below. The guard shall unlock the door only to permit

(1) The entrance of:

- (a) The Secretary of Agriculture
- (b) The Administrator of the Service
- (c) Officials of the Bureau of the Census who cooperate in issuing the Joint Cotton Ginning and Production Report
- (d) Employees of the Service and other persons whose presence is required in the preparation of the report and who have written permission from the Chairman
- (e) Other officials and employees of the Department having written authority from the Secretary of Agriculture, or from the Administrator of the Statistical Reporting Service

(2) The delivery to the Board rooms of mail, telegrams, written communications, or supplies for use of the Board

(3) Notification by the Chairman to the guard of delay in completion of a Board report (see subparagraph 333d) or by the Chairman or the Secretary of the Board to convey emergency instructions essential to completion of a report

(4) The departure of

- (a) The Secretary of Agriculture the Chair-

man, and such other persons as may be designated at the time by the Chairman, for the purpose of proceeding, under guard, to the room provided for the release of the report.

(b) Any person in the case of extreme emergency, in which event a member of the guard shall accompany and remain with such person until the release of the report

(c) All persons in case of fire or other serious emergency

### 333 APPROVAL AND RELEASE OF REPORTS

a *Approval*—Upon the completion of any Board reports specified in subparagraph 328a of these regulations, a copy must be signed by the Chairman, Secretary, and each member of the Board, and approved in writing by the Secretary of Agriculture before it is released. The Chairman, accompanied by a member of the guard and not less than two other persons, shall take copies of the approved report from the Board rooms to the release room before the time specified for the publication and release of the report.

b *Release officer*.—A designated representative of the Secretary of Agriculture shall act as release officer and shall provide in the release room suitable telegraph and telephone facilities for all persons desiring such facilities for the transmission of the report upon its official release

c *Procedure*—Upon the arrival in the Board release room of the Chairman and persons accompanying him, the release officer shall cause all persons other than the Chairman to remain within a prescribed area until the release of the report, the limits of which area shall be not less than 6 feet from the telephones, telegraph instruments, and tables or shelves provided for distribution of copies of the report. The Chairman then shall place copies of the report, face down beside each instrument, and additional copies face down upon the tables or shelves provided for that purpose. At the exact time provided for the official issuance of each report the release officer shall inform those present that the report is released to the public and permit access to the copies of the report. The release officer then shall notify the guard at the door of the Board rooms that the report has been released and the guard thereupon shall unlock the doors of the Board rooms

## USDA REGULATIONS GOVERNING CROP REPORTS

d *Delay in releasing reports*—In the event that the report should not be completed and approved for issuance at the designated time, the Chairman within 10 minutes of the time designated for the release of the report, shall notify the guard of the time when the report will be ready for release. The guard immediately shall notify the release officer, who, in turn, shall notify all persons who are present in the release room for the purpose of receiving the report. In order that telephone communication with the Board rooms may not be reestablished before the crop report is completed and released, the release offi-

cer also shall notify the employee in charge of the central Department telephone switchboard of the delay.

334 **ACKNOWLEDGEMENT OF REGULATION.**—The Deputy Administrator of the Statistical Reporting Service shall cause to be delivered, or exhibited, a copy of this regulation to each employee of the Service or other person having access to crop report data in advance of publication. The Deputy Administrator or an authorized representative shall obtain from each such person a certification which shall be an acknowledgement that such person has read this regulation and will be governed by it.

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## Laws Governing Crop Reports

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(All references are to United States Code)

### GENERAL

#### Title 7, Section 2202

The Department of Agriculture shall be an executive department under the supervision and control of a Secretary of Agriculture, who shall be appointed by the President, by and with the advice and consent of the Senate

#### Title 7, Section 2204

The Secretary of Agriculture shall procure and preserve all information concerning agriculture which he can obtain by means of books and correspondence and by practical and scientific experiments, accurate records of which experiments shall be kept in his office, by the collection of statistics, and by any other appropriate means within his power, he shall collect new and valuable seeds and plants, shall test, by cultivation, the value of such of them as may require such tests, shall propagate such as may be worthy of propagation, and shall distribute them among agriculturists.

#### Title 7, Section 411a

*Monthly crop report, contents, issuance, approval by Secretary of Agriculture.*—The monthly crop report, which shall be gathered as far as practicable from practical farmers, shall be printed and distributed on or before the twelfth day of each month, and shall embrace statements of the conditions of crops by States, in the United States, with such explanations, comparisons, and information, as may be useful for illustrating the above matter, and it shall be submitted to and officially approved by the Secretary of Agriculture, before being issued or published

#### Title 18, Section 1902

*Disclosure of crop information and speculation thereon*—Whoever, being an officer, employee or person acting for or on behalf of the United States or any department or agency thereof, and

having by virtue of his office, employment or position, become possessed of information which might influence or affect the market value of any product of the soil grown within the United States, which information is by law or by the rules of such department or agency required to be withheld from publication until a fixed time, willfully imparts, directly or indirectly, such information, or any part thereof, to any person not entitled under the law or the rules of the department or agency to receive the same, or, before such information is made public through regular official channels, directly or indirectly speculates in any such product by buying or selling the same in any quantity, shall be fined not more than \$10,000 or imprisoned not more than ten years, or both

No person shall be deemed guilty of a violation of any such rules, unless prior to such alleged violation he shall have had actual knowledge thereof

#### Title 18, Section 1905

*Disclosure of confidential information generally.*—Whoever, being an officer or employee of the United States or of any department or agency thereof, publishes, divulges, discloses, or makes known in any manner or to any extent not authorized by law any information coming to him in the course of his employment or official duties or by reason of any examination or investigation made by, or return, report or record made to or filed with, such department or agency or officer or employee thereof, which information concerns or relates to the trade secrets, processes, operations, style of work, or apparatus, or to the identity, confidential statistical data, amount or source of any income, profits, losses, or expenditures of any person, firm, partnership, corporation, or association, or permits any income return or copy thereof or any book containing any abstract or particulars thereof to be seen or examined by any person except as provided by law,



shall be fined not more than \$1,000, or imprisoned not more than one year, or both, and shall be removed from office or employment

#### Title 18, Section 2072

*False crop reports*—Whoever, being an officer or employee of the United States or any of its agencies, whose duties require the compilation or report of statistics or information relating to the products of the soil, knowingly compiles for issuance, or issues, any false statistics or information as a report of the United States or any of its agencies, shall be fined not more than \$5,000 or imprisoned not more than five years, or both

### COTTON

#### Title 7, Section 471

*Statistics and estimates of grades and staple length of cotton, collection and publication*—The Secretary of Agriculture is authorized and directed to collect and publish annually, on dates to be announced by him, statistics or estimates concerning the grades and staple length of stocks of cotton, known as the carry-over, on hand the 1st day of August of each year in warehouses and other establishments of every character in the continental United States, and following such publication each year, to publish, at intervals in his discretion, his estimate of the grades and staple length of cotton of the then current crop. Provided, That not less than three such estimates shall be published with respect to each crop. In any such statistics or estimates published, the cotton which on the date for which such statistics are published may be recognized as tenderable on contracts of sale of cotton for future delivery under the United States Cotton Futures Act, shall be stated separately from that which may be untenderable under said act

#### Title 7, Section 476

*Acreage reports*—The Secretary of Agriculture shall cause to be issued a report on or before the 12th day of July of each year showing by States and in toto the estimated acreage of cotton planted, to be followed on or before the 12th day of August with an estimate of the acreage for har-

vest and on or before the 12th day of December with an estimate of the harvested acreage

#### Title 7, Section 475

*Cotton crop reports*—The Secretary of Agriculture shall cause to be issued as of the first of each month during the cotton growing and harvesting season from August to January inclusive, reports describing the condition and progress of the crop and stating the probable number of bales which will be ginned, these reports to be issued simultaneously with the cotton-ginning reports of the Bureau of the Census relating to the same dates, the two reports to be issued from the same place at 3 o'clock postmeridian on or before the 12th day of the month to which the respective reports relate. No such report shall be approved and released by the Secretary of Agriculture until it shall have been passed upon by a cotton-crop reporting board consisting of five members or more to be designated by him, not less than three members of the board shall be supervisory field statisticians of the Department of Agriculture who are located in different sections of the cotton-growing States, are experienced in estimating cotton production and have first hand knowledge of the condition of the cotton crop based upon recent field observations. A majority of the members of the board shall be familiar with the methods and practices of producing cotton.

#### Title 12, Section 1141j(d)

*Governmental publication, predictions as to cotton prices prohibited*—The inclusion in any governmental report, bulletin, or other such publication hereafter issued or published of any prediction with respect to cotton prices is prohibited. Any officer or employee of the United States who authorizes or is responsible for the inclusion in any such report, bulletin, or other publication of any such prediction, or who knowingly causes the issuance or publication of any such prediction, shall upon conviction thereof, be fined not less than \$500 or more than \$5,000, or imprisoned for not more than five years, or both. Provided, That this subdivision shall not apply to the Governor of the Farm Credit Administration when engaged in the performance of his duties herein provided

## LAWS GOVERNING CROP REPORTS

Annual appropriation acts contain a similar prohibition in this form, "No part of the funds appropriated by this Act shall be used for the payment of any officer or employee of the Department who, as such officer or employee, or on behalf of the Department of any division, commission or bureau thereof, issues, or causes to be issued, any prediction, oral or written, or forecast, except as to damage threatened or caused by insects and pests, with respect to future prices of cotton or the trend of same." Pub L 87-879, Oct 24, 1962

### Title 13, Section 42

*Contents of reports, number of bales of linter; distribution, publication by Department of Agriculture —*

(a) The statistics of the quantity of cotton ginned shall show the quantity ginned from each crop prior to August 1, September 1, September 15, October 1, October 15, November 1, November 15, December 1, December 15, January 1, January 15, February 1, and March 1, but the Secretary may limit the canvasses of August 1 and September 1 to those sections of the cotton-growing States in which cotton has been ginned

(b) The quantity of cotton consumed in manufacturing establishments, the quantity of baled cotton on hand, the number of active consuming cotton spindles, the number of active spindle-hours, and the statistics of cotton imported and exported shall relate to each month, and shall be published as soon as possible after the close of the month

(c) In collecting and publishing statistics of cotton on hand in warehouses and other storage establishments, and of cotton known as the "carry-over" in the United States, the Secretary shall ascertain and publish as a separate item in the report of cotton statistics the number of bales of linters as distinguished from the number of bales of cotton

(d) The Secretary shall furnish to the Department of Agriculture immediately prior to the publication of each report of that Department regarding the cotton crop, the latest available statistics hereinbefore mentioned, and the De-

partment of Agriculture shall publish the same in connection with each of its reports concerning cotton

### Title 13, Section 43

*Records and reports of cotton ginner*—Every cotton ginner shall keep a record of the county or parish in which each bale of cotton ginned by him is grown and report at the completion of the ginning season but not later than the March canvass of each year a segregation of the total number of bales ginned by counties or parishes in which grown.

### Title 13, Section 44

*Foreign cotton statistics*—In addition to the information regarding cotton in the United States provided for in this subchapter, the Secretary shall compile, by correspondence or the use of published reports and documents, any available information concerning the production, consumption, and stocks of cotton in foreign countries, and the number of cotton-consuming spindles in such countries. Each report published by the Department of Commerce or agency or bureau thereof regarding cotton shall contain an abstract of the latest available information obtained under the provisions of this section, and the Secretary shall furnish the same to the Department of Agriculture for publication in connection with the reports of that department concerning cotton in the same manner as in the case of statistics relating to the United States.

### Title 13, Section 45

*Simultaneous publication of cotton reports*—The reports of cotton ginned to the dates as of which the Department of Agriculture is also required to issue cotton crop reports shall be issued simultaneously with the cotton crop reports of that department, the two reports to be issued from the same place at 3 o'clock postmeridian on or before the 12th day of the month to which the respective reports relate

**APPLES****Title 7, Section 411b**

*Estimates of apple production*—Estimates of apple production shall be confined to the commercial crop

**NAVAL STORES****Title 7, Section 2248**

*Statistics relating to turpentine and rosin*—The Secretary of Agriculture is authorized and directed to collect and/or compile and publish annually, and at such other times, and in such form and on such date or dates as he shall prescribe, statistics and essential information relating to spirits of turpentine and rosin produced, held, and used in the domestic and foreign commerce of the United States

**PEANUTS****Title 7, Section 951**

*Collection and publication, facts required, submission of report*—The Secretary of Agriculture is authorized and directed to collect and publish statistics of raw peanuts shelled, unshelled, and crushed, and peanut oil, in the United States, received, processed, shipped, and owned by or in the possession of warehousemen, brokers, cleaners, shellers, dealers, growers' cooperative associations, crushers, salters, manufacturers of peanut products, and owners other than the original producers of peanuts. Provided, That the Secretary may, in his discretion, omit for any period of time to collect such statistics from any or all salters of peanuts or manufacturers of peanut products who used, during the calendar year preceding that for which statistics are being collected, less than thirty thousand pounds of shelled and unshelled peanuts. Such statistics shall show the quality of peanuts in such details as to kinds—Virginias, Runners, Spanish and imported varieties—as the Secretary shall deem necessary for the purposes of this chapter. All reports except those required from persons owning or operating peanut picking or threshing machines shall be submitted monthly in each year, except as otherwise prescribed by the Secretary

**TOBACCO****Title 7, Section 501**

*Collection and publication, facts required, de-*

*teriorated tobacco*—The Secretary of Agriculture is authorized and directed to collect and publish statistics of the quantity of leaf tobacco in all forms in the United States and Puerto Rico, owned by or in the possession of dealers, manufacturers, quasi-manufacturers, growers' cooperative associations, warehousemen, brokers, holders, or owners, other than the original growers of tobacco. The statistics shall show the quantity of tobacco in such detail as to types, groups of grades, and such other subdivisions as to quality, color, and/or grade for particular types, as the Secretary of Agriculture shall deem to be practical and necessary for the purposes of this section and sections 502 to 508 of this title, shall be summarized as of January 1, April 1, July 1, and October 1 of each year, and an annual report on tobacco statistics shall be issued. Provided, That the Secretary of Agriculture shall not be required to collect statistics of leaf tobacco from any manufacturer of tobacco who, in the first three quarters of the preceding calendar year, according to the returns of the Commissioner of Internal Revenue or the record of the Treasurer of Puerto Rico, manufactured less than thirty-five thousand pounds of tobacco, or from any manufacturer of cigars who, during the first three quarters of the preceding calendar year, manufactured less than one hundred and eighty-five thousand cigars, or from any manufacturer of cigarettes who, during the first three quarters of the preceding year, manufactured less than seven hundred and fifty thousand cigarettes. And provided further, That the Secretary of Agriculture may omit the collection of statistics from any dealer, manufacturer, growers' cooperative association, warehouseman, broker, holder, or owner who does not own and/or have in stock, in the aggregate, fifty thousand pounds or more of leaf tobacco on the date as of which the reports are made. For the purposes of this section and sections 502 to 508 of this title any tobacco which has deteriorated on account of age or other causes to the extent that it is not merchantable or is unsuitable for use in manufacturing tobacco products shall be classified with other nondescript tobacco and reported in the 'N' group of the type to which it belongs

# Crop production



Release:  
July 11, 1974  
3:00 P.M. ET

## HIGHLIGHTS

Corn acreage for grain harvest, at 67.6 million, is 9 percent (5.8 million acres) more than 1973 and 18 percent above 1972.

Soybean acreage to be harvested for beans, at 52.5 million, is 7 percent (3.9 million) below last year but 15 percent above 1972.

All cotton acreage planted is estimated at 14.4 million, 15 percent above 1973, but 3 percent below the March Intentions.

Sorghum acreage for grain harvest, at 14.6 million is 8 percent (1.4 million) below last year.

All wheat production is forecast at a record high 1,925 million bushels, 12 percent (214 million bushels) above the previous high set last year and 25 percent above 1972.

Winter wheat production, at a record high 1,403 million bushels, is 128 million bushels (8 percent) below last month's forecast, but still 10 percent (133 million bushels) above last year's previous high record and 18 percent above 1972.

Spring wheat other than durum is forecast at a record high 422 million bushels, 18 percent (65 million bushels) above last year. Durum wheat, at 100 million bushels, is 18 percent (15.3 million bushels) above 1973.

All tobacco acreage is estimated at 966 thousand acres, up 9 percent from 1973. Flue-cured production is forecast at 1,272 million pounds, 10 percent above last year.

Summer potato production is forecast at 23.9 million cwt., 11 percent above the 1973 crop of 21.5 million cwt.

Acreage estimates are based on surveys conducted about June 1 and include acreage planted or intended to be planted and acreage intended for harvest. Significant acreages of corn and soybeans remained to be planted at the time of the surveys. The usual follow-up surveys will be conducted during July to determine final plantings. Special acreage surveys are also being conducted in 8 States that experienced a late planting season. Changes indicated by the July surveys will be shown in the August Crop Production Report issued August 12.

**UNITED STATES DEPARTMENT OF AGRICULTURE**

STATISTICAL REPORTING SERVICE CROP REPORTING BOARD

CrPr 2-2 (7-74)

WASHINGTON, D.C. 20250

## CROP REPORT SUMMARY

Production expectations for winter<sup>1</sup> wheat are down 8 percent from a month earlier, according to the Crop Reporting Board, but still a record high. The all wheat production forecast is 12 percent above 1973 and, if realized, will be a record large crop. Expectations for barley and rye production are down from last year's crop while oat production increased.

Planted acreage of feed grains (barley, corn, oats and sorghum) is estimated at 123 million acres, 1 percent above 1973. Increased corn acreage more than offset decreases in the other feed grains.

Acreage of all principal crops planted for harvest in 1974 totaled 329 million acres, 3 percent or 8 million acres more than 1973. The change reflects sharp increases in wheat and corn.

Total acreage of all crops for harvest, at 320 million acres is up 3 percent or 8 million acres from a year earlier.

The final orange production forecast for the 1973-74 season at 218.1 million boxes is 3 percent below the 1972-73 record crop. Summer potato production is forecast at 23.9 million cwt., 11 percent above the 1973 summer crop.

The CROP PRODUCTION report contains State and National estimates with related information on selected agricultural commodities. These data were prepared and adopted by the Crop Reporting Board which consists of commodity statisticians from the Statistical Reporting Service's field offices and Washington headquarters.

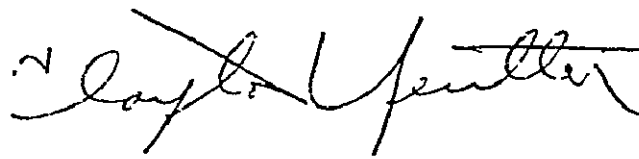
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ACTING SECRETARY OF AGRICULTURE

UNITED STATES CROP SUMMARY  
(Domestic units)

Crop and unit		Acreage (In thousands)		Yield per acre		Production (In thousands) 1/		
		Harvested	For	1973	Indi-	1973	June 1	July 1
		1973	harvest	1974	cated	1974	1974	1974
Corn for grain 2/	Bu	61,760	67,589	91.4		5,643,256		
White corn (10 Sts.) 3/	"	509	651	81.4		41,421		
Sorghum for grain	"	15,940	14,589	58.8		936,587		
Oats	"	14,110	13,994	47.0	48.9	663,860		684,021
Barley	"	10,527	8,554	40.3	40.9	424,483		349,780
All wheat	"	53,875	63,682	31.8	30.2	1,711,400		1,925,059
Winter	"	38,407	46,350	33.1	30.3	1,269,653	1,531,355	1,402,945
Durum	"	2,974	3,677	28.5	27.2	84,860		100,168
Other Spring	"	12,494	13,655	28.6	30.9	356,887		421,946
Rice	Cwt. 4/	2,170.2	2,388.9	4,277		92,823		
Rye	Bu	1,038	910	25.4	24.2	26,398		22,020
Soybeans for beans	"	56,416	52,470	27.8		1,566,518		
Flaxseed	"	1,725	1,696	9.5		16,437		
Peanuts harvested for nuts	Lb	1,495.7	1,501.3	2,323		3,473,837		
Popcorn	"	148.8	184.1	3,303		491,418		
Cotton 5/	Bale 4/	12,500.7	14,362.6	498		12,958.0		
Hay, all	Ton	62,190	60,546	2.16		134,608		
Alfalfa hay	"	27,529	26,747	2.85		78,343		
All other hay	"	34,661	33,799	1.62		56,265		
Dry edible beans 6/	Cwt. 4/	1,397.7	1,570.5	1,208		16,886		
Dry edible peas	" 4/	136.4	218.3	1,221		1,665		
Potatoes	"							
Summer	"	125.1	130.5	172	183	21,478		23,911
Sweet potatoes	"	113.2	121.0	111		12,534		
All tobacco	"	885.8	965.8	1,962		1,737,569		
Flue-cured tobacco	"							
Types 11-14	Lb.	575.1	623.0	2,011	2,042	1,156,659		1,272,451
Sugarbeets	Ton	1,219.9	1,200.5	20.1		24,507		
Sugarcane for sugar and seed	"	740.8	748.8	34.9		25,823		
Pasture & range 7/	Pct.			87	82			
Apples, com'l crop	Lb.					6,205.0		6,187.3
Peaches 8/	"					2,604.9	2,872.7	2,941.4
Pears	Tons					720.1		704.6
Sweet cherries 9/	"					153.6	144.2	135.0
Tart cherries 9/	"					87.0	123.7	123.5
Apricots	"					157.7	94.7	94.1
Nectarines (CA)	"					87.0	95.0	100.0
Plums (CA)	"					97.0	115.0	130.0
Dried prunes (CA)	"					203.0	155.0	155.0
Almonds (CA)	"					134.0	170.0	180.0
Walnuts	"					174.0		141.2
						Indicated		
						June 1	July 1	
Citrus Fruits 10/						1972 - 73	1973 - 74	1973 - 74
Oranges	Box					224,260	216,000	218,100
Grapefruit	"					65,640	64,500	65,000
Lemons	"					22,200	17,400	17,400

1/ Apples and peaches in million pounds. 2/ Includes white corn 3/ 1973 and 1974 totals are not for comparable States. 4/ Yield in pounds. 5/ Planted acres. 6/ 1973 acreage, yield, and production changed to include data for Indiana and Illinois. 7/ Pasture and range condition as of first of month. The 1963-72 average is 82 percent. 8/ Includes culls and cannery diversions for California clingstone peaches as follows in million pounds 1973-162.0. 9/ Estimates in June 1 column include forecast in the Great Lakes States as of June 15. 10/ Season begins with the bloom of the first year shown and ends with the completion of harvest the following year.

CROP PRODUCTION, July 1974

Crop Reporting Board, SRS, USDA

UNITED STATES CROP SUMMARY  
(Metric units)

Crop	Area		Yield per hectare		Production		
	Harvested:	For			Indicated		
	1973	harvest	1973	1974	1973	June 1	July 1
		1974				1974	1974
	1,000 hectares		Quintals		1,000 metric tons		
Corn for grain	24,994	27,353	57.3		143,339		
White corn (10 Sts.)	206	263	51.1		1,052		
Sorghum for grain	6,451	5,904	36.9		23,789		
Oats	5,710	5,663	16.9	17.5	9,636		9,929
Barley	4,260	3,462	21.7	22.0	9,242		7,615
All wheat	21,803	25,771	21.4	20.3	46,577		52,391
Winter	15,543	18,757	22.2	20.4	34,554	41,677	38,182
Durum	1,204	1,488	19.2	18.3	2,310		2,726
Other spring	5,056	5,526	19.2	20.8	9,713		11,483
Rice	878.3	966.8	47.9		4,210		
Rye	420	1368	16.0	15.2	671		559
Soybeans for beans	22,831	21,234	18.7		42,634		
Flaxseed	698	1686	6.0		417		
Peanuts harvested for nuts	605.3	607.6	26.0		1,576		
Popcorn	60.2	74.5	37.0		223		
Cotton 1/	5,058.9	5,812.4	5.58		2,821.3		
Hay, all	25,168	24,502	48.5		122,114		
Alfalfa hay	11,141	10,824	63.8		71,071		
All other hay	14,027	13,678	36.4		51,043		
Dry edible beans	565.6	635.6	13.5		766		
Dry edible peas	55.2	88.3	13.8		76		
Potatoes							
Summer	50.6	52.8	192	205	974		1,085
Sweetpotatoes	45.8	49.0	124		569		
All tobacco	358.5	390.8	22.0		788		
Flue-cured tobacco							
Types 11-14	232.7	252.1	22.6	22.9	525		577
Sugarbeets	493.7	485.8	450		22,232		
Sugarcane for sugar and seed	299.8	303.0	781		23,426		
Apples, com'l crop					2,814.5		2,806.5
Peaches					1,181.6	1,303.0	1,334.2
Pears					653.3		639.2
Sweet cherries					139.3	130.8	122.5
Tart cherries					78.9	112.2	112.0
Apricots					143.1	85.9	85.4
Nectarines (CA)					78.9	86.2	90.7
Plums (CA)					88.0	104.3	117.9
Dried prunes (CA)					184.2	140.6	140.6
Almonds (CA)					121.6	154.2	163.3
Walnuts					157.9		128.1
Citrus Fruits							
Oranges					1972-73	June 1	July 1
Grapefruit					8,835	1973-74	1973-74
Lemons					2,428	8,510	8,596
					766	2,405	2,424
						600	600

1/ Planted area.

## "ALL CROP" Prospects Mostly Fair to Excellent

Prospects for "all crops" as reported by farmers on July 1 were mostly fair to excellent. Better prospects than a year ago were indicated for most of the Northwest States, which were hit by drought last year. Prospects improved in Ohio, Georgia, Pennsylvania and New York where wet conditions were hurting prospects last year. Dry conditions are responsible for poor and very poor prospects in portions of Montana, Utah, Colorado, New Mexico and Texas. In contrast, wetness caused poor to very poor prospects in some areas of Mississippi and Illinois.

## COOL WEATHER SLOWS ROW CROP GROWTH

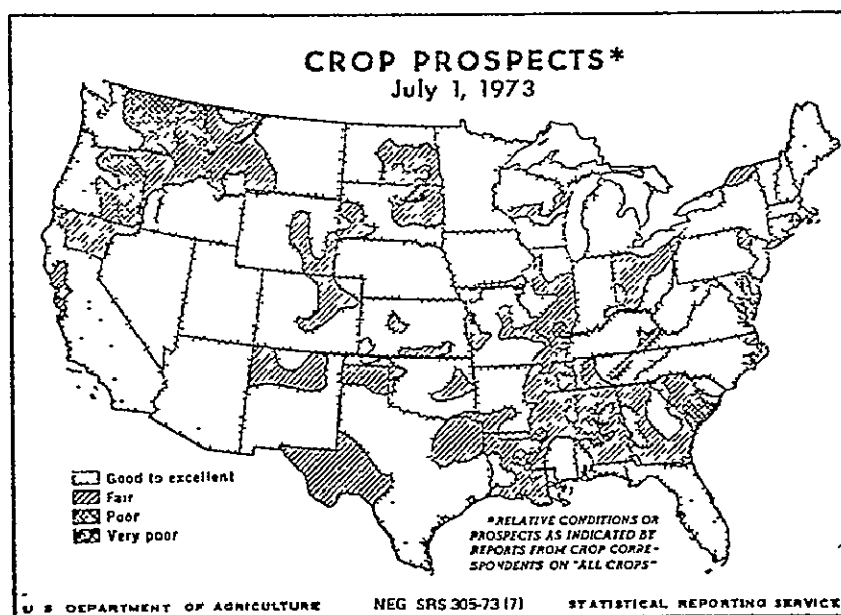
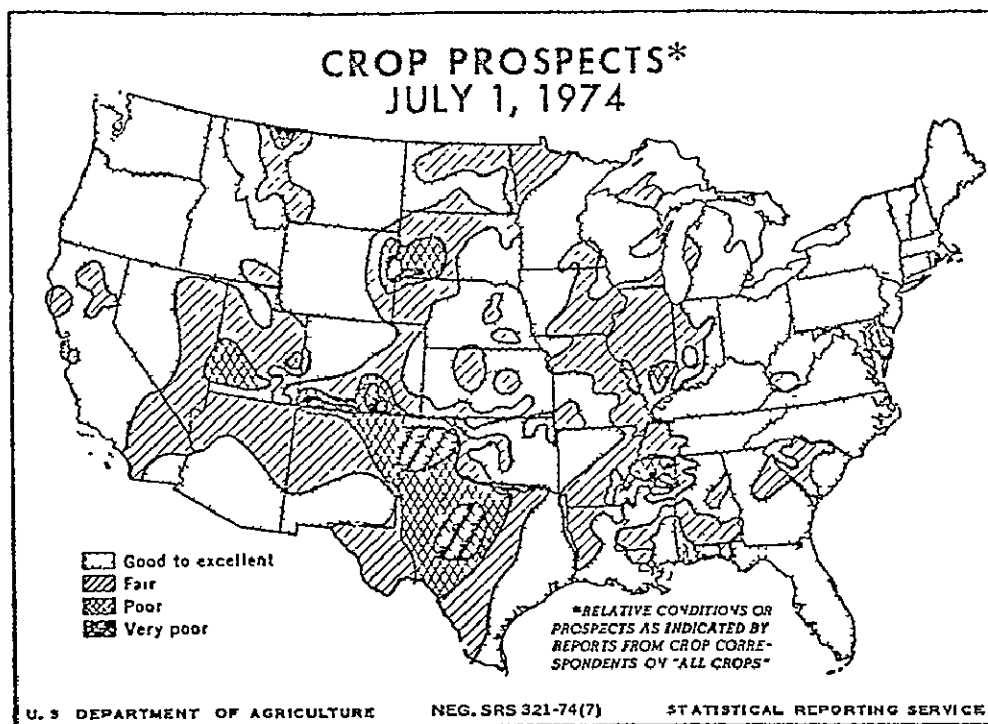
Cool weather dominated east of a line from central Texas to North Dakota during June, while west of the line temperatures ranged up to 9 degrees above normal. The month began with a major storm extending from the upper Great Lakes down into Texas. Tornadoes, thunderstorms, high winds and torrential rains struck 15 States, causing flash flooding in Louisiana, Arkansas, Kansas, Oklahoma, Missouri, and Texas. The southern half of Arkansas received over twice the normal amount of rainfall. Throughout the eastern half of the country, moisture was highly variable. Much of the Corn Belt had above normal rainfall and subnormal temperatures, further delaying planting progress and development of corn and soybeans. The northern half of Illinois and parts of Indiana and Iowa were very wet. The wet conditions also interrupted spraying, cultivation and haymaking. The western half of the Nation was exceptionally dry except for a portion of the Central Great Plains. Alabama and southern Louisiana were also dry. Planting of cotton and sorghum in Texas was slowed considerably by soil moisture shortage.

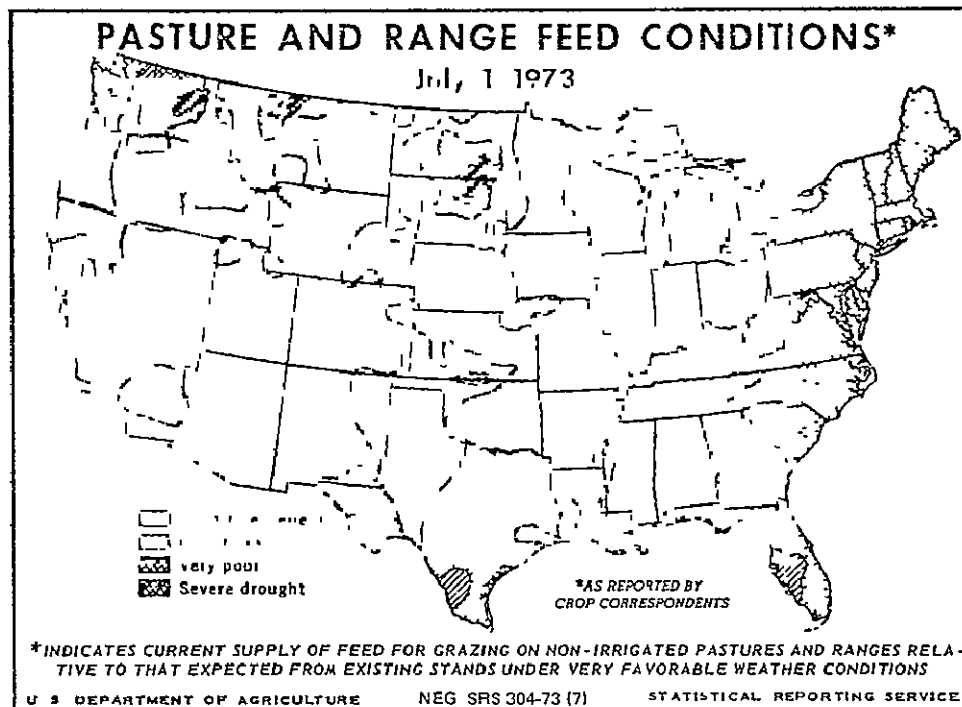
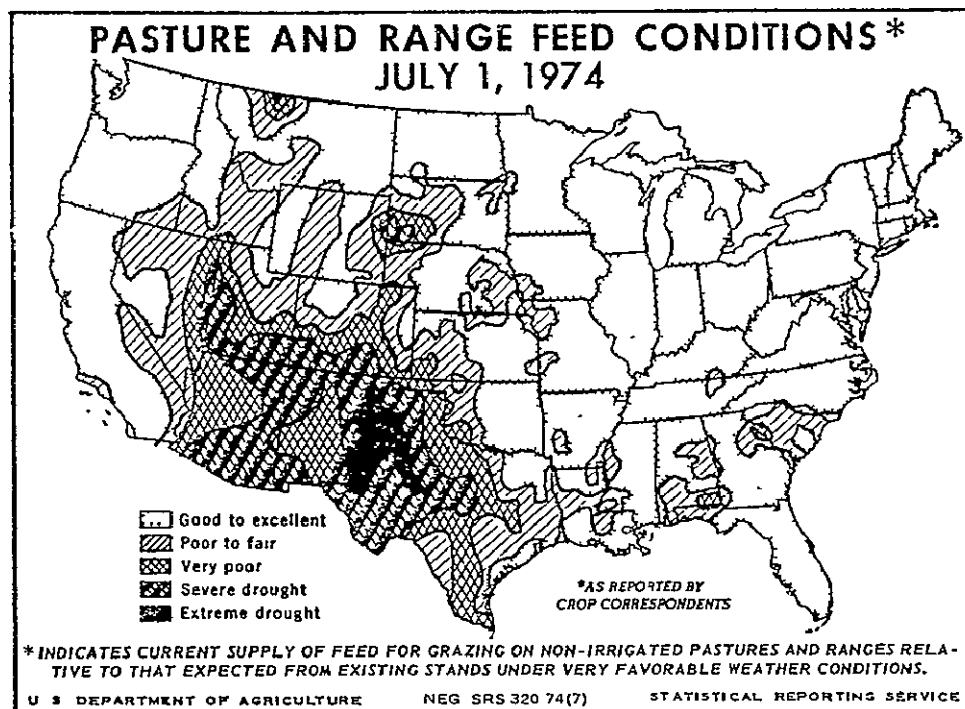
Much of the east North Central region received above normal precipitation. Below normal precipitation occurred in the west North Central States except for areas in South Dakota, central Nebraska and western Kansas. Central Wisconsin received subnormal rainfall as did northeast Indiana, northwest Ohio and southeastern Michigan. Some areas in northern Illinois received more than two times their normal amount of rainfall. Near or above normal precipitation was received during June along the South Atlantic Coast and the northern portion of the North Atlantic States. Much of Florida received over twice the normal amount of rainfall.

Most of the western States received less than half the normal June precipitation. The exceptions were: north central California, central and eastern Colorado and southeast Wyoming. No precipitation fell in an area that included southern Utah, southern California and nearly all of Arizona and Nevada.

Temperatures averaged well above normal over the western half of the Nation during June and cooler than normal to the east. In the west, much of Arizona, Utah, Nevada, Idaho, and parts of southern California and eastern Oregon experienced temperatures as much as 7 degrees above normal. An area in north central Arizona had temperatures 9 degrees above normal. The Nation's greatest temperature departures below normal occurred in portions of northwest Arkansas, southern Missouri, southwest Illinois, northern Alabama, eastern Tennessee, and southern Kentucky where temperatures were as much as 6 degrees below normal.







C-67

## ROW CROPS GENERALLY IN GOOD CONDITION

Row crops in the North Central States are in generally good condition, although development is considerably behind normal progress because of the wide variation in planting dates and cool wet weather in May and June. Moisture supplies were adequate to surplus during much of June, but topsoil moisture shortages were becoming general by July 1. Considerable replanting of corn was necessary in Iowa, Indiana and Illinois because of poor germination and wet conditions. Height of corn plants in the Corn Belt is averaging shorter than last year. Corn in the Southern States is in mostly good condition. About one-fifth of the corn in Virginia and two-fifths in Alabama is silking. Early corn is tasseling in Kentucky and Tennessee.

In the North Central States, soybeans that have emerged are making slow growth due to the cool temperatures. Planting was nearing completion at 93 percent done and for the first time this year planting is ahead of last year's progress of 91 percent. Soybean planting in the south made good progress with final plantings being made following harvest of winter wheat. Mississippi planting trails the Nation with only 63 percent of their intended acreage in by July 1 compared with 86 percent in 1973. Most emerged acreage is in good condition but development is generally behind last year and normal in most States.

The sorghum crop is in good to excellent condition but moisture supplies are becoming short in many of the major sorghum States. Dry conditions slowed planting in Texas and farmers were nearly 95 percent done by July 1. Conditions improved in early June and planting in Nebraska was completed by mid-June, while planting in Kansas was 90 percent done by July 1, equal to last year and normal progress. In south Texas, sorghum matured rapidly and early harvest was underway from the Coastal Bend to lower Rio Grande Valley by July 1.

Cotton crop development was slowed by cool temperatures in much of the major producing areas, but condition of the crop remains good. Control of weeds and insects has been successful in most areas and was still active with the application of herbicides, insecticides and cultivation on July 1.

## SMALL GRAIN HARVEST AHEAD OF NORMAL

Winter wheat harvest advanced as far north as the southern Corn Belt States by July 1. Good drying conditions enabled farmers to make excellent progress combining winter wheat. Harvest continues well ahead of 1973 and normal for most States. Texas wheat was 95 percent combined by July 1, Kansas wheat harvest had advanced to 85 percent complete, the most harvested for this time since 1956. Hot temperatures in Colorado pushed the crop to maturity and 3 percent was harvested by July 1, much ahead of normal. Oat harvest was nearing completion in Texas, Arkansas, South Carolina and Georgia and getting underway in Kansas. The crop is in various stages of development in the North Central States: Wisconsin 20 percent headed, Michigan 26 percent, Minnesota 9 percent and Ohio 90 percent headed. Barley combining is ahead of last year's progress in the southeastern areas.

CORN• Corn planted for all purposes is estimated at 77.7 million acres, down 1 percent from the March Intentions Report but up 9 percent from 1973 and up 16 percent from 1972. All regions of the country except the Western showed increased plantings from last year. Acreage is up 9 percent in both the North Central and South Atlantic regions, 13 percent in the South Central region, and 5 percent in the North Atlantic region but down 3 percent in the Western region.

The 67.6 million acres of corn intended for grain in 1974 is 9 percent more than 1973 and 18 percent more than 1972. Acreage for grain is up 9 percent in the Corn Belt, South Atlantic and North Atlantic States, 14 percent in the South Central States but down 4 percent in the Western States.

Corn planting got off to a good start this year, in sharp contrast to 1973 when the spring was unusually wet. In the North Central States, seeding was 52 percent completed by May 12 compared with 30 percent last year and 40 percent average. However, rains and wet fields during the next 4 weeks through mid-June, slowed planting activities to a rate comparable with last year but well behind average. Planting in the Corn Belt was virtually completed by June 23 with the exception of Illinois and Indiana where 5 percent remained. In the Southern and Eastern States, planting was nearing completion by June 9.

By the end of June Iowa corn was nearly all emerged but heavy rains and erosion reduced stands in parts of the State. Corn development varied throughout the North Central region with late plantings just emerging. Replanting portions of fields was necessary in several States. Early acreages in the southern Corn Belt were cultivated for the last time and laid by.

Through June 30, the corn crop in the Corn Belt was reported in fair to good condition with mostly adequate soil moisture. However, plant height averaged shorter than last year. In Illinois, corn fields averaged 20 inches high compared with 23 inches last year and 37 inches in 1972. Minnesota corn averaged 18 inches, 6 inches shorter than in 1973. The outlook for corn in Iowa improved and weed control was reported good except where no herbicide was applied. Early corn in Nebraska was growing rapidly but late plantings showed signs of heat stress and lack of surface moisture. Cool, dry weather occurred throughout much of the South Central region but corn was growing well. Corn silking was 40 percent in Alabama and 10 percent in Tennessee, both ahead of last year.

WHITE CORN Growers in the 10 States surveyed planted 694,000 acres to white corn varieties. Acreage intended for grain totals 651,000 acres. The white corn acreage is included in the all-corn acreage estimates in this publication.

A comparison of the 1974 10-State total with previous years cannot be made as estimates for two States (Nebraska and Ohio) were discontinued after 1973 and two new States (Alabama and Georgia) were added this year. Growers in the 8 States for which comparable data are available planted 523,000 acres, 1 percent above the 517,000 acres last year and 18 percent above the 443,000 acres planted in 1972. Acreage intended for grain, at 491,000 acres is virtually the same as 1973 but 20 percent above 1972 for the comparable States.

SORGHUM Sorghum planted for all purposes is 17.8 million acres, down 8 percent from 1973 but 3 percent above the 1972 acreage. Plantings are 6 percent under the intentions of March 1. Producers expect to harvest 14.6 million acres of sorghum for grain, a decrease of 8 percent from the 1973 acreage but 9 percent greater than 1972.

Texas, with 7.6 million acres, is down 6 percent from 1973 plantings. Kansas, the second largest sorghum State with 4.1 million acres, is off 13 percent from the previous year, while Nebraska showed a 2 percent decrease. The greatest decline by a major sorghum State occurred in Oklahoma with plantings at only 80 percent of the 1973 acreage.

Texas expects to harvest 6.4 million acres for grain, 8 percent less than a year earlier, but 18 percent more than 1972. Acreage harvested for grain in Missouri is expected to be the same as 1973 while Oklahoma will harvest 15 percent fewer acres. Decline of 10 percent in acreage harvested for grain is anticipated in Kansas and 5 percent in both Nebraska and Colorado.

In most States, planting got off to a slow start this spring because of wet soils and competition from other crops. Planting progress in most States caught up or moved ahead of normal by mid-June with Nebraska nearly complete at that time. Drought conditions delayed planting of dryland acreage in Texas which was over 90 percent complete by July 1, while Kansas and Missouri were nearing the 90 percent level. Sorghums in Texas, Oklahoma, and southwest Kansas were dry, but elsewhere in the major producing States, conditions were good. Arizona sorghum is in all stages from just planted to harvested. In New Mexico the irrigated acreage was up and growing but most dryland acreage had not been planted.

RICE: Growers will harvest rice on an estimated 2.4 million acres this year, up 10 percent from last year and 31 percent from the acreage harvested in 1972. If realized, this will be the second highest of record, exceeded only by 1954, when 2.6 million acres were harvested.

The rice crop in the Southern States was in good to excellent condition on July 1 and developing normally. Some early fields had been harvested in the upper Gulf Coast area of Texas by that date and rice was heading in southwest Louisiana. The California crop was also developing normally on July 1.

Planting in the Southern States was completed by the normal time this year due to generally favorable planting conditions and the crop got a good start. This is in contrast to last year when flooding and wet fields delayed the completion of seeding considerably so that a few fields in Texas were still being seeded in late June. Planting of the 1974 crop in California's important Sacramento Valley was delayed by wet fields this year but was complete by the third week in June.

ALL WHEAT: Production of all wheat is forecast at a record 1,925 million bushels, 12 percent more than last year's record crop and 25 percent above the 1972 crop. Changes between the July 1 forecast and final estimates have averaged 37 million bushels during the past decade - ranging from 3 million to 88 million bushels. In five of the ten years, the July forecast was above the final by an average of 40 million and five times it was below by an average of 33 million bushels.

Acreage of all wheat for harvest, at 63.7 million acres, is 18 percent above last year and the largest since 1953 when 67.8 million acres were harvested. The indicated yield of 30.2 bushels per acre is below both the 1973 average of 31.8 and the 1972 average yield of 32.7 bushels.

WINTER WHEAT: Winter wheat production is forecast at a record high 1,403 million bushels, 10 percent above the previous high set last year and 18 percent above 1972. The increase from a year earlier is the result of a sharp increase in acreage harvested. The 8 percent decline from the forecast published June 10 is attributed to continued dry weather in some areas, excess moisture in others, and advancing disease damage.

Changes in production between the July 1 forecasts and final estimates of production after harvest have averaged 37 million bushels over the past decade, ranging from 2 million to 80 million bushels. The July 1 forecast was above the final estimate 7 of the 10 years by an average of 38 million bushels and below 3 times by an average of 35 million bushels.

Acreage to be harvested for grain is estimated at 46.4 million, 21 percent above last year, 33 percent above 1972 and the largest acreage on record since 1953 when 46.9 million acres were harvested. Indicated acreage for grain is 89.1 percent of the planted acreage estimate of 52.0 million acres. This compares with 89.0 percent harvested for grain last year and 82.6 percent in 1972.

## HARVESTED ACREAGE OF CROPS, UNITED STATES, 1965-74

YEAR	CORN		OATS	BARLEY	SORGHUMS		FEED
	ALL	FOR GRAIN			ALL	FOR GRAIN	GRAINS
1,000 ACRES							
1965	64,616	55,392	18,522	9,166	16,600	13,029	96,109
1966	65,867	57,002	17,877	10,250	15,966	12,813	97,942
1967	70,034	60,694	16,110	9,230	18,351	14,988	101,022
1968	64,605	55,980	17,708	9,732	17,302	13,890	97,310
1969	63,063	54,574	17,971	9,557	16,835	13,437	95,539
1970	66,077	57,358	18,638	9,725	16,476	13,568	99,289
1971	73,523	64,047	15,772	10,151	20,026	16,301	106,271
1972	66,237	57,421	13,525	9,707	16,728	13,368	94,021
1973	71,093	61,760	14,110	10,527	18,919	15,940	102,337
1974	76,807	67,589	13,994	8,554	17,400	14,589	104,726
WHEAT							
WINTER		DURUM	OTHER SPRING	ALL	RICE	RYE	FOOD GRAINS
2/							
1,000 ACRES							
1965	37,586	2,296	9,678	49,542	1,792.7	1,473	52,826
1966	38,616	2,423	8,574	49,613	1,967.2	1,276	52,856
1967	45,039	2,754	10,560	58,353	1,970.1	1,063	61,386
1968	41,929	3,621	9,215	54,765	2,353.4	996	58,114
1969	36,303	3,420	7,423	47,146	2,128.4	1,291	50,565
1970	32,702	2,105	8,757	43,564	1,814.7	1,427	46,806
1971	32,359	2,864	12,451	47,674	1,817.9	1,754	51,246
1972	34,840	2,550	9,894	47,284	1,817.9	1,084	50,186
1973	38,407	2,974	12,494	53,875	2,170.2	1,038	57,083
1974	46,350	3,677	13,655	63,682	2,388.9	910	66,981
PEANUTS							
FLAXSEED		FOR NUTS	POPCORN	COTTON	ALL HAY	EDIBLE BEANS	EDIBLE PEAS
1,000 ACRES							
1965	2,775	1,438.3	205.3	13,612.7	67,496	1,484	174
1966	2,576	1,420.7	207.1	9,552.6	64,356	1,486	175
1967	1,975	1,403.5	161.9	7,997.3	63,303	1,205	176
1968	2,092	1,438.4	185.3	10,159.3	60,922	1,424	181
1969	2,605	1,455.7	182.6	11,051.1	59,716	1,469	232
1970	2,848	1,467.0	136.5	11,155.0	61,492	1,409	256.9
1971	1,545	1,454.5	173.7	11,470.9	61,405	1,316	202.7
1972	1,151	1,486.4	157.0	12,983.8	59,821	1,402	135.1
1973	1,725	1,495.7	148.8	11,995.2	62,190	1,397.7	136.4
1974	1,696	1,501.3	184.1	60,546	1,570.5	218.3	
SUGARCANE							
SUGAR-BEETS		FOR SUGAR & SEED	POTATOES	SWEET-POTATOES	TOBACCO	PRINCIPAL CROPS HARVESTED	PLANTED
3/ 4/							
1,000 ACRES							
1965	1,248.5	617.0	1,383.1	168.1	976.9	287,758	297,215
1966	1,161.1	625.2	1,462.6	154.4	971.9	283,511	293,062
1967	1,122.1	627.6	1,459.9	139.5	959.8	295,447	305,781
1968	1,410.1	605.8	1,383.3	135.2	879.3	289,668	299,384
1969	1,540.5	535.6	1,415.5	136.9	918.3	280,586	291,153
1970	1,418.6	583.9	1,421.3	127.8	898.3	283,185	293,312
1971	1,341.9	648.1	1,391.3	113.6	837.6	295,319	306,153
1972	1,328.7	701.8	1,253.8	114.4	842.4	283,458	295,183
1973	1,219.9	740.8	1,303.7	113.2	885.8	311,500	320,311
1974	1,200.5	748.8		121.0	965.8	319,851	328,542

1/ CORN FOR GRAIN, OATS, BARLEY AND SORGHUM GRAIN. 2/ WHEAT, RYE AND RICE 3/ CROP ACREAGES INCLUDED ARE CORN, SORGHUM, OATS, BARLEY, WHEAT, RICE, RYE, SOYBEANS, FLAXSEED, PEANUTS, POPCORN, COTTON, (CURRENT YEAR HARVESTED ACREAGE ALLOWANCES FOR COTTON AND POTATOES ARE DERIVED BY SUBTRACTING AVERAGE ABANDONMENT FROM COTTON PLANTED ACREAGE AND INTENDED FALL POTATO ACREAGE), ALL HAY, DRY EDIBLE BEANS, DRY EDIBLE PEAS, POTATOES, SWEETPOTATOES, TOBACCO, SUGARCANE, AND SUGARBEETS. 4/ CROP ACREAGES INCLUDED ARE PLANTED FOR CORN, SORGHUM, OATS, BARLEY, DURUM AND OTHER SPRING WHEAT, RICE, SOYBEANS, FLAXSEED, PEANUTS, POPCORN, COTTON DRY EDIBLE BEANS, DRY EDIBLE PEAS, POTATOES (INCLUDED INTENDED PLANTINGS FOR FALL CROP) SWEETPOTATOES, AND SUGARBEETS; HARVESTED ACREAGE FOR WINTER WHEAT, RYE, ALL HAY, TOBACCO, AND SUGARCANE.

PLANTED ACREAGE OF CROPS, 1973 and 1974

STATE	WINTER		DURUM		OTHER SPRING		ALL	
	WHEAT 1/		WHEAT		WHEAT		WHEAT	
	1973	1974	1973	1974	1973	1974	1973	1974
1,000 ACRES								
ALA.	140	185					140	185
ARIZ.	236	250					236	250
ARK.	305	470					305	470
CALIF.	625	813	2	3			627	816
COLO.	2,520	2,720			41	50	2,561	2,770
DEL.	29	35					29	35
FLA.	55	52					55	52
GA.	165	215					165	215
IDAHO	900	1,060			300	395	1,200	1,455
ILL.	1,350	1,850					1,350	1,850
IND.	740	1,440					740	1,440
IOWA	33	31					33	31
KANS.	10,800	12,000					10,800	12,000
KY.	241	460					241	460
LA.	60	80					60	80
MD.	125	158					125	158
MICH.	585	950					585	950
MINN.	36	44	60	97	1,960	2,550	2,056	2,691
MISS.	135	195					135	195
MO.	980	1,450					980	1,450
MONT.	2,200	2,750	185	245	1,850	2,000	4,235	4,995
NEBR.	2,800	3,000					2,800	3,000
NEV.	9	11			7	9	16	20
N.J.	50	60					50	60
N.MEX.	390	411					390	411
N.Y.	151	220					151	220
N C	200	290					200	290
N DAK.	80	130	2,680	3,190	6,350	6,440	9,110	9,760
OHIO	755	1,580					755	1,580
OKLA.	6,000	6,800					6,000	6,800
OREG.	1,020	1,120			80	140	1,100	1,260
PA	276	360					276	360
S C.	120	180					120	180
S.DAK	793	990	115	215	1,530	1,870	2,438	3,075
TENN.	207	350					207	350
TEX.	4,600	5,600					4,600	5,600
UTAH	235	259			50	60	285	319
VA.	195	300					195	300
WASH.	2,730	2,800			615	460	3,345	3,260
W.VA.	17	21					17	21
WIS.	17	57			12	24	29	81
WYO.	250	265			16	23	266	288
U.S.	43,155	52,012	3,042	3,750	12,811	14,021	59,008	69,783
1/ ACREAGE SEEDED PRECEDING FALL								

PLANTED ACREAGE OF CROPS, 1973 AND 1974

STATE	RYE 1/		OATS 1/		BARLEY		SWEETPOTATOES	
	1973	1974	1973	1974	1973	1974	1973 2/	1974
1,000 ACRES								
ALA			84	110			4.5	5.5
ARIZ					145	120		
ARK			110	110			1.5	1.7
CALIF			366	344	1,070	1,020	1.4	6.0
COLO	71	24	126	126	285	262		
DEI	52	50			29	30		
FLA			32	33				
GA	446	385	198	230	15	12	8.0	8.5
IDAHO			81	81	835	720		
ILL	85	83	550	540	18	18		
IND	55	51	359	275	13	13		
IOWA	16	22	1,850	1,900				
KANS	155	130	140	300	90	80		
KY	35	50	50	42	67	60		
LA			24	24			36.0	36.0
MAINE			44	45				
MD	78	80	31	31	110	110	2.2	2.2
MICH	165	150	350	370	24	21		
MINN	100	80	2,690	2,270	903	804		
MISS.			70	80			9.5	9.5
MO.	106	80	90	250	17	16		
MONT			510	460	2,100	1,400		
NEBR.	212	140	575	690	38	37		
NEV.			8	8	18	16		
N J	71	75	9	10	39	40	1.6	1.8
N.MEX					31	28		
N.Y.	130	130	370	390	13	13		
N C	100	100	160	170	74	70	25.0	28.0
N DAK	122	122	2,120	1,720	2,910	2,270		
OHIO	50	80	600	530	15	16		
OKLA	315	280	350	320	270	150		
OREG	60	60	175	145	320	225		
PA	79	85	405	420	172	160		
S C	142	130	150	160	29	30	2.0	2.5
S DAK	260	229	2,480	2,430	671	560		
TENN.	27	30	120	123	29	28	3.2	3.0
TEX	350	250	2,100	1,800	150	90	10.0	11.0
UTAH			23	21	147	144		
VA	200	200	90	85	117	125	7.8	7.7
WASH	32	50	112	125	390	335		
W.VA			30	22	11	11		
WIS.	23	35	1,500	1,450	22	21		
WYO.	25	24	76	70	148	148		
U S	3,562	3,205	19,208	18,310	11,335	9,203	117.7	123.4

1/ INCLUDES ACREAGE PLANTED PRECEDING FALL

2/ REVISED



## CORN

STATE	ACREAGE PLANTED FOR ALL PURPOSES			ACREAGE FOR GRAIN		
				HARVESTED		
	1972	1973	1974	1972	1973	1974
	1,000 ACRES					
ALA.	631	694	715	545	610	620
ARIZ.	26	23	21	15	9	10
ARK.	38	34	36	28	21	24
CALIF.	358	412	416	215	235	240
COLO.	690	718	682	374	438	410
CONN.	50	50	50			
DEL.	196	200	204	179	186	192
FLA.	365	400	437	307	340	371
GA.	1,620	1,840	2,000	1,490	1,670	1,760
IDAHO	108	110	100	25	28	27
ILL.	9,540	9,980	10,680	9,225	9,670	10,340
IND.	5,050	5,400	5,760	4,884	5,240	5,600
IOWA	11,255	11,800	13,000	10,600	11,150	12,100
KANS.	1,570	1,900	2,100	1,250	1,540	1,800
KY.	1,131	1,160	1,290	968	1,010	1,130
LA.	100	85	95	86	65	80
MAINE	36	37	40			
MD.	564	600	630	443	500	530
MASS.	34	35	35			
MICH.	2,120	2,100	2,310	1,722	1,690	1,850
MINN.	5,650	6,200	6,940	4,899	5,520	6,180
MISS.	220	200	205	163	148	160
MO.	2,720	2,800	3,200	2,500	2,600	2,970
MONT.	80	92	99	6	11	12
NEBR.	5,680	6,400	6,800	5,135	5,850	6,300
NEV.	3	3	3			
N.H.	18	19	19			
N.J.	105	120	127	52	75	90
N.MEX.	49	51	58	21	21	25
N.Y.	922	1,000	1,100	270	360	440
N.C.	1,450	1,550	1,720	1,280	1,400	1,570
N.DAK.	495	544	533	159	180	169
OHIO	3,333	3,300	3,950	3,090	3,040	3,700
OKLA.	121	128	124	71	87	91
OREG.	43	43	42	11	9	10
PA.	1,440	1,490	1,530	900	1,040	1,080
R.I.	4	4	4			
S.C.	435	500	600	375	430	530
S.DAK.	3,280	3,760	3,650	2,414	2,630	2,570
TENN.	670	683	760	480	508	595
TEX.	580	750	980	460	640	835
UTAH	80	90	95	8	13	14
VT.	84	88	90			
VA.	706	734	750	502	550	570
WASH.	106	112	95	48	68	50
W.VA.	95	100	107	53	63	70
WISC.	3,051	3,200	3,490	2,143	2,090	2,450
WYO.	70	72	71	25	25	24
U.S.	66,972	71,611	77,743	57,421	61,760	67,589

CROP PRODUCTION, JULY 1974

CROP REPORTING BOARD, SRS, USDA

## WINTER WHEAT

STATE	ACREAGE			YIELD PER ACRE			PRODUCTION		
	HARVESTED		FOR HARVEST 1974	1972	1973	INDI- CATED 1974	1972	1973	INDI- CATED 1974
	1972	1973							
	1,000 ACRES			BUSHEL			1,000 BUSHEL		
ALA	110	88	130	20.0	23.0	23.0	2,200	2,024	2,990
ARIZ	170	216	235	67.0	70.0	67.0	11,390	15,120	15,745
ARK	296	217	430	37.0	28.0	26.0	10,952	6,076	11,180
CALIF	483	570	764	48.0	54.0	56.0	23,184	30,780	42,784
COLO	2,150	2,400	2,500	24.0	24.5	23.0	51,600	58,800	57,500
DEL	25	26	31	33.0	35.0	37.0	825	910	1,147
FLA	42	30	35	15.0	22.0	18.0	630	660	630
GA	140	120	160	20.0	27.0	22.0	2,800	3,240	3,520
IDAHO	772	780	970	45.0	42.0	44.0	34,740	32,760	42,680
ILL	1,200	1,260	1,760	45.0	30.0	30.0	54,000	37,800	52,800
IND	826	703	1,380	48.0	35.0	37.0	39,648	24,605	51,060
IOWA	33	27	29	37.5	31.0	36.0	1,238	837	1,044
KANS	9,400	10,400	11,200	33.5	37.0	29.5	314,900	384,800	330,400
KY	216	164	380	32.5	33.0	31.0	7,020	5,412	11,780
LA	30	18	40	23.0	22.0	25.0	690	396	1,000
MD	110	116	145	35.0	34.0	36.0	3,850	3,944	5,220
MICH	535	568	940	40.0	35.0	38.0	21,400	19,880	35,720
MINN	26	32	40	30.0	37.0	30.0	780	1,184	1,200
MISS	160	100	170	31.0	27.0	24.0	4,960	2,700	4,080
MO	925	850	1,310	39.0	30.0	29.0	36,075	25,500	37,990
MONT	1,790	2,080	2,650	27.0	26.5	29.0	48,330	55,120	76,850
NEBR	2,509	2,680	2,900	37.0	35.0	35.0	92,833	93,800	101,500
NEV	7	8	10	75.0	70.0	70.0	525	560	700
N J	35	38	50	38.0	36.0	38.0	1,330	1,368	1,900
N MEX	170	289	191	25.5	29.5	18.0	4,335	8,526	3,438
N Y	140	140	210	37.0	36.0	39.0	5,180	5,040	8,190
N C	200	160	255	31.0	35.0	37.0	6,200	5,600	9,435
N DAK	66	73	116	33.0	32.0	30.0	2,178	2,336	3,480
OHIO	1,029	720	1,540	45.0	32.0	40.0	46,305	23,040	61,600
OKLA	3,900	5,260	6,200	23.0	30.0	21.0	89,700	157,800	130,200
OREG	828	940	1,080	42.5	35.0	42.0	35,190	32,900	45,360
PA	269	264	350	32.0	28.0	35.0	8,608	7,392	12,250
S C	136	101	168	20.0	25.0	25.0	2,720	2,525	4,200
S DAK	705	666	880	36.0	32.0	30.0	25,380	21,312	26,400
TENN	240	144	310	32.0	31.0	33.0	7,680	4,464	10,230
TEXAS	2,000	3,400	3,300	22.0	29.0	18.0	44,000	98,600	59,400
UTAH	205	207	238	26.5	24.0	25.0	5,433	4,968	5,950
VA	218	175	275	37.0	37.0	38.0	8,066	6,475	10,450
WASH	2,490	2,120	2,660	48.0	35.0	42.0	119,520	74,200	111,720
W VA	14	12	17	35.0	31.0	36.0	490	372	612
WISC	20	16	56	32.0	35.0	40.0	640	560	2,240
WYO	220	229	245	35.0	23.0	26.0	7,700	5,267	6,370
U S	34,840	38,407	46,350	34.0	33.1	30.3	1,185,225	1,269,653	1,402,945

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CROP PRODUCTION JULY, 1974

CROP REPORTING BOARD, SRS, USDA

## OATS

STATE	ACREAGE			YIELD PER ACRE			PRODUCTION		
	HARVESTED		FOR HARVEST 1974	1972	1973	INDI- CATED 1974	1972	1973	INDI- CATED 1974
	1972	1973							
	1,000 ACRES			BUSHEL			1,000 BUSHEL		
ALA	18	20	30	31.0	37.0	40.0	558	740	1,200
ARK	100	67	74	78.0	55.0	55.0	7,800	3,685	4,070
CALIF	133	110	105	51.0	42.0	50.0	6,783	4,620	5,250
COLO	37	41	54	42.5	43.0	41.0	1,573	1,763	2,214
DEL 1/	3			40.0			120		
FLA	13	11	12	32.0	38.0	36.0	416	418	432
GA	65	70	90	38.0	50.0	46.0	2,470	3,500	4,140
IDAHO	56	60	60	54.0	50.0	50.0	3,024	3,000	3,000
ILL	440	430	440	63.0	46.0	54.0	27,720	19,780	23,760
IND	201	261	210	59.0	48.0	55.0	11,859	12,528	11,550
IOWA	1,250	1,325	1,600	57.0	48.0	52.0	71,250	63,600	83,200
KANS	167	100	220	44.0	40.0	39.0	7,348	4,000	8,580
KY	10	12	10	41.0	42.0	38.0	410	504	380
LA	14	8	12	44.0	43.0	46.0	616	344	552
MAINE	32	34	35	62.0	46.0	57.0	1,984	1,564	1,995
MD	25	26	26	49.0	52.0	55.0	1,225	1,352	1,430
MICH	320	330	350	55.0	50.0	54.0	17,600	16,500	18,900
MINN	2,440	2,550	2,190	51.0	56.0	53.0	124,440	142,800	116,070
MISS	28	20	20	52.0	40.0	43.0	1,456	800	860
MO	150	41	140	46.0	34.0	35.0	6,900	1,394	4,900
MONT	246	270	270	48.0	38.0	42.0	11,808	10,260	11,340
NEBR	390	460	560	49.0	48.0	46.0	19,110	22,080	25,760
NEV	4	2	2	45.0	43.0	45.0	180	86	90
N J	6	6	7	45.0	43.0	48.0	270	258	336
N Y	280	325	360	45.0	55.0	57.0	12,600	17,875	20,520
N C	75	75	80	45.0	50.0	55.0	3,375	3,750	4,400
N DAK	2,070	1,800	1,550	51.0	41.0	40.0	105,570	73,800	62,000
OHIO	367	540	490	61.0	48.0	64.0	22,387	25,920	31,360
OKLA	155	194	175	37.5	41.0	33.0	5,813	7,954	5,775
OREG	95	110	95	52.0	54.0	50.0	4,940	5,940	4,750
PA	362	375	405	46.0	47.0	53.0	16,652	17,625	21,465
S C	72	68	75	38.0	42.0	44.0	2,736	2,856	3,300
S DAK	2,000	2,140	2,250	49.0	47.0	45.0	98,000	100,580	101,250
TENN	30	29	30	37.0	40.0	45.0	1,110	1,160	1,350
TEX	360	650	380	27.0	41.0	24.0	9,720	26,650	9,120
UTAH	13	14	13	52.0	54.0	48.0	676	756	624
VA	43	46	44	42.0	42.0	47.0	1,806	1,932	2,068
VT 1/	3			36.0			108		
WASH	35	50	70	58.0	44.0	53.0	2,030	2,200	3,710
W VA	14	18	12	45.0	46.0	46.0	630	828	552
WIS	1,350	1,370	1,400	55.0	41.0	57.0	74,250	56,170	79,800
WYO	53	52	48	50.0	44.0	41.0	2,650	2,288	1,968
U S	13,525	14,110	13,994	51.2	47.0	48.9	691,973	663,860	684,021

1/ ESTIMATES DISCONTINUED AFTER 1972.



# **crop reporting board reports**

**1974  
Issuance Dates  
and Contents**

DECEMBER 1973

CROP REPORTING BOARD  
STATISTICAL REPORTING SERVICE • U S DEPARTMENT OF AGRICULTURE • WASHINGTON, D C

The Crop Reporting Board of the Statistical Reporting Service issues the periodic reports listed and described in this booklet. Copies are available at the Washington, D. C. Office immediately after release. For most reports, mailing lists are maintained for regular distribution, without charge.\* Send requests to:

Crop Reporting Board  
Statistical Reporting Service, USDA  
Washington, D. C. 20250

Please indicate the title(s) of reports and provide the Zip Code in your address

*\*NOTE Copies of reports designated on pages 9-10 are available only at address listed.  
Mailing lists are also maintained by the designated offices.*

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The Department of Agriculture announces the following schedule of 1974 RELEASE DATES for the various crop and livestock reports issued by the Crop Reporting Board. All reports are issued from Washington, D C unless specified otherwise. The time of the release when shown is that in effect for Government offices in Washington, D C.

# GENERAL CROP PRODUCTION REPORTS (Released at 3 00 P. M.)

## Crop Production by States, 1974 (unless indicated otherwise).

Stocks of hay on farms as of January 1, indicated production of 1973-74 crop citrus fruits, acreage, yield per acre and production of cotton and potatoes (Winter), and prospective plantings of potatoes (Spring). Revisions for 1973 crop potatoes (Spring).	Jan. 9
Annual summary of acreage, yield per acre and production for 1973 including revised data for 1972. <i>Note</i> State estimates for fruit and nuts included in <i>Noncitrus Fruit and Nut Annual Summary</i> .	Jan. 16
Prospective plantings for corn, spring wheat, oats, barley, all sorghums, soybeans, cotton and flaxseed (35 States).	Jan. 22
Indicated production of 1973-74 crop citrus fruits, yield per acre as of February 1 and production of potatoes (Winter).	Feb. 8
Indicated production of 1973-74 crop citrus fruits, acreage of potatoes (Spring), and yield per acre as of March 1 and production of potatoes (Winter).	Mar. 8
Prospective plantings for corn, durum wheat, other spring wheat, oats, barley, flaxseed, cotton, rice, all sorghums, potatoes, sweet potatoes, dry edible beans, dry edible peas, soybeans, peanuts, and sugarbeets, acreage for harvest of hay and tobacco Revised acreage for 1973 crop potatoes (Summer)	Mar. 14
Condition of pastures and ranges, indicated production of 1973-74 crop citrus fruits, yield per acre as of April 1, and production of potatoes (Spring). Revisions for 1973 crop acreage, yield per acre, and production of peanuts. Also revised yield and production for 1973 crop potatoes (Summer).	Apr. 10
Acreage remaining for harvest as of May 1, yield per acre and indicated production of winter wheat, percentage of winter wheat seedings harvested for grain for United States, condition of pastures and ranges; stocks of hay on farms, yield per acre and indicated production of potatoes (Spring), indicated production of 1973-74 crop citrus fruits, peaches in 9 early Southern States and almonds, preliminary production of maple sirup (1974 crop). Also revisions for 1973 cotton acreage, yield per acre, production of lint and seed, value of lint, disposition and value of cottonseed, monthly marketings of lint by farmers and 1973 tobacco acreage, yield per acre, production, price and value of production (by types and classes) and final revisions for 1972 tobacco; revision of production for almonds, bananas, papayas and taro 1973 crop, and final revision of production for 1972-73 crop citrus fruits.	May 8
Acres for harvest for winter wheat, indicated yield per acre as of June 1 for winter wheat, indicated production of winter wheat, peaches, Bartlett pears (Pacific coast States), cherries (Western States), apricots, nectarines, California plums, California prunes, almonds, and 1973-74 crop citrus fruits, yield per acre and production of potatoes (Spring), condition of pastures and ranges. Planted and harvested acres for mint oil. Also revisions for acreage, yield per acre, production, price and value of production of mint for oil, sugarbeets and sugarcane for 1973 (sugarbeet price and value for the United States only), production of beet and cane sugar, sugarbeet pulp, and products of cane harvested for sugar.	June 10

## Crop Production, continued

Planted acreage for cotton, planted acreage and acreage for harvest of all corn, white corn, winter wheat, durum wheat, other spring wheat, oats, barley, rye, flaxseed, rice sweetpotatoes, dry edible beans, dry edible peas, soybeans, peanuts, sorghum, popcorn, and sugarbeets, harvested acreage for hay, tobacco, potatoes (Summer), and sugarcane for sugar and seed. Indicated yield per acre and production as of July 1 are forecast for winter wheat, durum and other spring wheat, oats, barley, rye, and flue-cured tobacco; also potatoes (Summer). Production, based on average yield adjusted for trend, will be projected for the U. S. for corn for grain, flaxseed, rice, sugar crops, dry edible beans, dry edible peas, hay, tobacco (except flue-cured), soybeans for beans, sorghum grain and peanuts for nuts. Indicated production of wheat by classes (U. S.), apples (Commercial), apricots, peaches, pears, cherries (Western States), California grapes, nectarines, California plums, California prunes, almonds, walnuts and 1973-74 crop citrus fruits, condition of pastures and ranges. Revised estimates (1973 crop) of acreage for harvest, yield per acre and production of sweetpotatoes and popcorn, and planted acreage for popcorn.

July 11

Planted acreage for corn, soybeans, sorghum, durum wheat, other spring wheat and cotton. Acreage for harvest, indicated yield per acre and indicated production as of August 1 of corn for grain, winter wheat, durum and other spring wheat, oats, barley, rye, flaxseed, cotton, rice, hay, sorghum grain, dry edible beans, dry edible peas, soybeans for beans, peanuts harvested for nuts, potatoes (Summer), sweetpotatoes, tobacco, sugarbeets, sugarcane for sugar and seed, broomcorn, mint for oil, and hops; acreage for harvest for potatoes (Fall); indicated production of wheat by classes (U. S.), apples (Commercial), peaches, pears, grapes, plums and prunes (Michigan, Idaho, Washington, Oregon), walnuts; condition of pastures and ranges, and index of production by groups of crops for United States. Revised estimates for 1973 crop of harvested acreage, yield per harvested acre and production of broomcorn, and potatoes (Fall).

Aug. 12

Acreage for harvest, indicated yield per acre and indicated production as of September 1 of corn for grain, winter wheat, durum and other spring wheat, oats, barley, flaxseed, cotton, rice, sorghums for grain, dry edible beans, dry edible peas, soybeans for beans, peanuts harvested for nuts, potatoes (Summer), sweetpotatoes, tobacco, sugarbeets, sugarcane for sugar and seed, broomcorn, mint for oil, and hops; indicated production of wheat by classes (U. S.), pears, grapes, plums and prunes (Michigan, Idaho, Washington, Oregon), California prunes, walnuts, filberts, pecans, coffee revised 1973 crop, condition of pastures and ranges. Index of production by groups of crops for United States is also shown.

Sept. 11

Acreage for harvest, indicated yield per acre and indicated production of corn for grain, all wheat, durum and other spring wheat, flaxseed, cotton, rice, sorghums for grain, hay, dry edible beans, soybeans for beans, peanuts harvested for nuts, potatoes (Fall), sweetpotatoes, tobacco, sugarbeets, sugarcane for sugar and seed, and hops, indicated production of wheat by classes (U. S.), apples (Commercial), grapes, plums and prunes (Michigan, Idaho, Washington, Oregon), cranberries, filberts, pecans and 1974-75 crop citrus fruits; condition of pastures and ranges; and index of production by groups of crops for United States. Seeded winter wheat forage supplies. Intentions to plant 1975 crop potatoes (Winter). Revised acreage, yield, and production for 1974 crop potatoes (Winter).

Oct. 10

Acreage for harvest, indicated yield per acre and indicated production as of November 1, of corn for grain, cotton, rice, sorghums for grain, dry edible beans, soybeans for beans, peanuts harvested for nuts, potatoes (Fall), tobacco, sugarbeets, and sugarcane for sugar and seed. Production of California prunes, cranberries, filberts, and 1974-75 crop citrus fruits; condition of pastures and ranges, and index of production by groups of crops for United States. Seeded winter wheat forage supplies. Cropping practice data for selected States -- Corn plant population, corn and soybean row-width and regular varieties.

Nov. 8

## Crop Production, continued

Acreage, indicated yield per acre and indicated production of burley tobacco, cotton, and pecans. Indicated production of 1974-75 crop citrus fruits. Acreage, yield per acre, and production for wheat, oats, barley, rye, dry edible beans, rice, and potatoes (Fall) including revised data for preceding year except for potatoes (Fall). Also price and value for wheat, oats, barley, and rye. Production of rice by length of grain classes and dry edible beans by commercial classes. Seeded winter wheat forage supplies, condition of pastures and ranges.

Dec. 10

Seeded acreage and indicated production of winter wheat, 1975 crop.

Dec. 23

\* \* \*

### OTHER REPORTS CONCERNING CROPS

(Released at 3:00 P. M., except cranberries -- Aug. 20 -- 1:00 P. M.)

#### Crop Values:

Season average prices and value of production of principal crops for 1973 including revised data for 1972. *Note: State estimates for fruit and nuts included in Noncitrus Fruit and Nut Annual Summary.*

Jan. 16

#### Field Crops

Production, disposition, value, 1972-73 crops, (except cotton, tobacco, sugar, potatoes and sweetpotatoes).

May 10

#### Grain Stocks.

Wheat (all and durum), rye, corn, oats, barley, sorghum grain, soybeans and flaxseed stocks on farm, off-farm, and in all positions, first of month, by States Jan. 24, Apr. 24, July 24, and Oct. 24 (Soybeans excluded in October).

Quarterly

#### Soybean Stocks

Soybean stocks on-farm, off-farm, and in all positions on September 1, by States.

Sept. 20

#### Peanut Stocks and Processing:

Stocks end of previous month, millings, production and disappearance of milled products previous month, United States Jan. 25, Feb. 25, Mar. 25, Apr. 25, May 24, June 25, July 25, Aug. 26, Sept. 26, Oct. 25, Nov. 25, Dec. 23 and seasonal report, Sept. 19.

Monthly

#### Rice Stocks:

Rough and milled rice stocks by position, first of month, by States and stocks by length of grain classes (Southern Area and California) Jan. 24, Apr. 24, Aug. 26, Oct. 24 (California only, in October).

Quarterly

#### Hop Stocks

Grower, dealer and brewer stocks, Mar. 1 and Sept. 1, United States.

Mar. 19 &  
Sept. 17

#### Popcorn

Acreage planted and for harvest. (Also included in July Crop Production Report.)

July 12

#### Potato Stocks

Grower and local dealer storage stocks in fall crop producing areas, first of month, by States Jan. 9, Feb. 8, Mar. 8, April 10, Dec. 10.

#### Potatoes and Sweetpotatoes

Production, farm disposition, and value by States, and utilization of Irish Potatoes, U S , 1973

Aug. 23

#### Vegetables--Fresh Market

Quarterly prospective acreage for harvest and intentions to plant for selected crops winter quarter, Jan. 8, spring quarter, April 8, summer quarter, July 8, fall quarter, October 8 Quarterly acreage harvested and production winter quarter, May 8, spring quarter, August 8, summer quarter, Nov. 8, fall quarter, Jan. 8 1975. Acreage for harvest and production of selected commercial crops March 8, June 7, and Sept. 9.



## Other Reports Concerning Crops, continued

### Vegetables--Processing:

Intentions to plant, Mar. 29, planted acres, June 27, production forecasts, July 9, Aug. 8, Sept. 10, and annual summary, Dec. 19.

Cucumbers for Pickles Stocks and revisions, production forecast for spinach. Nov. 15

### Celery-

Monthly plantings and acreage remaining for harvest (Florida, California, Ohio, New York, and Michigan). Jan. 4, Feb. 5, Mar. 5, Apr. 4, May 6, June 4, July 5, Aug. 5, Sept. 4, Oct. 4, Nov. 5, Dec. 5. Monthly

### Onion Stocks in Storage-

Total stocks in common and cold storage, as of January 1. Jan. 18

### Fruits:

Noncitrus Fruit and Nut Annual Summary: Production, use, price and value, 1973 crop with comparisons. Jan. 14

Noncitrus Fruit and Nut Mid-Year Supplement: Production, utilization, price, and value, 1973 crop with comparisons. July 11

Citrus: Production, use and value, 1973-74 crop with comparisons. Oct. 1

Cherry Production Mid-June production forecast of 1974 crop and utilization previous crop (New York, Ohio, Pennsylvania, Michigan, and Wisconsin). June 21

Cranberries: Indicated production, by States, 1974, RELEASED 1 00 P. M. Aug. 20

Apples: By varieties. Final 1973 crop and forecast 1974 crop. Aug. 14

Cherry Utilization. Revised production and utilization of 1974 crop. Oct. 7

### Seed Crops-

Forecast Reports -- Indicated acreage for harvest, yield per acre and production, by States, 1974.

Crimson Clover (Southern States)	June 20
Tall Fescue (Southern States)	July 16
Crimson Clover (Oregon)	Aug. 5
Tall Fescue (Oregon)	Aug. 15
Timothy	Aug. 22
Red Clover	Oct. 10
Alfalfa	Oct. 22

### Seed Crops:

Annual Summary: revised acreage, yield, production, price and value, disposition, supply and disappearance of field seeds. (Includes Crimson Clover, Tall Fescue, Timothy, Red Clover, Alfalfa, Lespedeza, Orchardgrass, Bentgrass, Red and Chewings Fescue, Hairy Vetch, Ladino Clover, Ryegrass, Merion Kentucky Bluegrass and Kentucky Bluegrass other than Merion.) May 30

### Other Seed Reports:

Seed Crops--Preliminary Estimates acreage, yield, production, price and value, supply and disappearance of field seeds.	Jan. 16
Acreage and Production of Vegetable Seeds, 1974 prospective and 1973 final.	Mar. 18
Stocks of Field Seeds Held by Dealers on June 30.	Aug. 2
Stocks of Vegetable Seeds Held by Dealers on June 30.	Aug. 16
Retail Seed Prices--Released 3 00 P. M April 30 September 30	

### Flowers and Foliage Plants 23 States:

Carnations, chrysanthemums, gladioli, roses and foliage plants. Production and sales, 1973 and intentions for 1974. March 27

### Mushrooms, U. S. Totals and Selected States:

Area in production, production, and value, July 1, 1973 -- June 30, 1974 and intentions for coming year. Aug. 21

## Other Reports Concerning Crops, continued

### Export Sales\*

Export Sales for U. S. wheat (by classes), wheat products, corn, barley, rye, oats, grain sorghum, rice, flaxseed, cotton (by staple length), cottonseed and soybean, oilcake and meal, linseed, cottonseed, soybeans, and the oil from the preceeding two crops, by country of destination. Released at 3:00 P. M. (Eastern time) on Friday of each week.

Weekly

\* \* \*

## LIVESTOCK REPORTS (Released at 3.00 P.M.)

### Cattle

Cattle, number, value and classes, by States, January 1, 1974. Number of calves born during 1973 by States. Cattle, number, and classes, July 1, 1973, major States and United States. Number of farms keeping cattle, milk cows, by States and United States.

Feb. 1

Cattle, number and classes, major States and United States, July 1, 1974. Expected number of calves born and to be born during 1973.

July 26

### Cattle on Feed:

Total number on feed as of January 1, 1974, by States and United States. Number of feed lots and fed marketings by size groups, 23 states January 18.

Annual

Total number on feed, number on feed by classes, by weight groups, marketings and placements, 23 States. Cattle sold for slaughter at selected markets January 18, April 18, July 18, and October 18.

Quarterly

Total number on feed, marketings and placements, in seven selected States. Cattle sold for slaughter at selected markets Jan. 18, Feb. 13, Mar. 13, Apr. 18, May 14, June 13, July 18, Aug. 14, Sept. 13, Oct. 18, Nov. 13, Dec. 13.

Monthly

### Hogs and Pigs:

March 1 inventory, number and classes, December 1973 - February 1974 farrowings and March - August 1974 farrowings indicated by breeding intentions, 14 Quarterly States.

Mar. 22

June 1 inventory, number and classes, December 1973 - May 1974 farrowings and June - November 1974 farrowings indicated by breeding intentions, major States and United States.

June 21

September 1 inventory, number and classes, June - August 1974 farrowings and September 1974 - February 1975 farrowings indicated by breeding intentions, 14 Quarterly States.

Sept. 20

December 1 inventory, number, value and classes, June - November farrowings and December 1974 - May 1975 farrowings indicated by breeding intentions, by States and United States. Number of farms keeping hogs, by States and United States.

Dec. 23

### Sheep and Goats:

Sheep, and goats (Texas only), number, value and classes, by States, January 1, 1974. Number of lambs saved during the year, by States. Number of farms keeping sheep, by States and United States

Jan. 28

### Sheep and Lambs on Feed

Number on Feed, major States, January 1974.

Jan. 16

Number on feed, seven States, March 1, 1974, and number early lambs, three States, March 1, 1974.

Mar. 14

Number on feed, seven States, November 1, 1974.

Nov. 14

#### Wool and Mohair

Number of sheep shorn, wool production, price by months, and value, by States, 1973. Number of goats clipped, mohair production, and value, Texas 1973.

April 12

#### Lamb Crop - Wool:

Number of lambs saved during the year, major States and United States, 1974.  
Number of sheep shorn and to be shorn during the year and wool production, major States and United States, 1974.

July 23

#### Meat Animals - Farm Production, Disposition and Income, by States, 1972 - 1973.

April 12

#### Livestock Slaughter and Meat Production (For Previous Month)

Number of head and live weight of cattle, calves, hogs, sheep and lambs slaughtered in commercial plants, by States. Red meat production by species and lard production, United States Jan. 29, Feb. 27, Mar. 28, April 29, May 30, June 28, July 30, Aug. 29, Sept. 27, Oct. 30, Nov. 27, Dec. 30.

Monthly

#### 1973 Revisions:

Slaughter by States and by months and total livestock slaughter, meat, and lard production, by quarters.

Apr. 29

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### POULTRY AND EGG REPORTS (Released at 3:00 P.M.)

#### Eggs, Chickens and Turkeys:

Number of layers on hand during preceding month, eggs per 100 layers, total eggs produced, and number of layers and rate of egg production per 100 layers as of first of current month, major States and United States. Egg production quarterly by States. Number of broiler and non-broiler chicks hatched during preceding month in commercial hatcheries, by States, number of chicken and turkey eggs in incubators, and poults hatched, by geographic divisions. Number of pullet chicks for broiler hatchery supply flocks placed during preceding month (total and domestic). Number of pullet chicks for egg type hatchery supply flocks placed during the preceding month (domestic). Number of chickens tested for pullorum disease by official State agencies during the preceding month, United States, by months, annual by States. Number of turkeys tested for pullorum disease by official State agencies during the preceding month by States, by months. Includes following special summaries.

Monthly

Potential layers and pullets not of laying age on farms as of the first of the month, by geographic divisions. Mar., June, Sept., and Dec.

#### Chicken Inventory -- December 1, 1973

Number and value of chickens on farms by States -- January.

Intentions to hold turkey breeder hens for the 1975 hatching season, major States -- September.

Released Jan. 18, Feb. 20 Mar. 19, Apr. 18 May 17, June 18, July 18, Aug. 16,  
Sept. 18, Oct. 18, Nov. 19, Dec. 18.

#### Layers and Egg Production (Annual):

Layers, potential layers and egg production, 1972 and 1973. Estimates of average number of layers on hand during each month, monthly rate of lay and egg production. Hens and pullets of laying age and rate of lay the first of each month, major States and United States, egg production quarterly by States, potential layers and pullets not of laying age by geographic regions. (Summary of revised data that appear currently.)

Feb. 20

#### Hatchery Production (Annual):

Number of broiler and non-broiler chicks hatched and poults hatched, by States, chicken and turkey eggs in incubators, by geographic regions. (Summary of revised data that appear currently.)

March 19

## Poultry and Egg Reports, continued

<b>Egg Products -- Liquid, Frozen, Dried, Production Under Federal Inspection</b>	
Production of egg products by classes and utilization by 4-week periods, United States, Jan. 9 (4-week period ending December 8, 1973), Feb. 6 (4-week period ending January 5, 1974), March 6 (Feb. 2, 1974), April 3 (March 2, 1974), April 30 (March 30, 1974), May 29 (April 27, 1974), June 24 (May 25, 1974), July 24 (June 30, 1974), August 23 (July 20, 1974), Sept. 20 (Aug. 17, 1974), Oct. 16 (Sept. 14, 1974), Nov. 15 (October 12, 1974), Dec. 12 (Nov. 9, 1974).	Monthly
<b>Poultry -- Slaughtered Under Federal Inspection and Poultry Used in Further Processing</b>	
Monthly number of head and pounds, quantity used in processing, cut-up and packaged under the USDA inspection service, United States, Jan. 4 (slaughter for month of November 1973), Feb. 1 (December 1973), March 7 (January 1974), April 4 (February 1974), May 2 (March 1974), June 3 (April 1974), July 3 (May 1974), Aug. 1 (June 1974), Sept. 3 (July 1974), Oct. 3 (August 1974), Nov. 1 (September 1974), Dec. 5 (October 1974).	Monthly
<b>Commercial Broiler Production and Broiler Chicks Placed in 21 States, 1973:</b>	
Estimates on number produced, live weight, price and gross income, by States. Number of broiler chicks placed and number of eggs set during 1973, by States, by weeks. Preliminary reports on broiler chicks placed and broiler-type eggs set are issued on Wednesday <u>1</u> / of each week in each of the 21 States covered by weekly reports.	March 6
<b>Chickens and Eggs Including Broiler Production:</b>	
Production, disposition, cash receipts and gross income, 1972 and 1973, by States.	April 3
<b>Turkeys</b>	
Breeder Hens Inventory, December 1, 1973 and Number Turkeys Raised, 1973 and Intentions 1974	
Number of light and heavy breed hens on farms and value, major States. Number of light and heavy breeds raised during preceding year and number indicated by producers to be raised during the year, major States.	Jan. 9
Number Raised, 1974	
Number of light and heavy breed turkeys raised and to be raised during the year, by States.	Aug. 23
Number Raised -- Production, and Gross Income, 1972 and 1973 by States:	
Number of light and heavy breeds raised, pounds produced, gross income and death loss of turkeys.	March 7

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## MILK AND DAIRY PRODUCTS REPORTS (Released at 3 00 P. M.)

<b>Milk Production</b>	
Number of milk cows, milk production per cow and total milk production for preceding month, major States and United States. Milk production by States quarterly. Includes special summaries of data relating to dairying, such as	Monthly
Revised milk cow numbers and milk production, by months, 1972 and 1973 -- February.	
Grain fed daily per milk cow -- January, April, July and October.	
Released Jan. 10, Feb. 11, Mar. 11, Apr. 11, May 9, June 11, July 12, Aug. 13, Sept. 12, Oct. 11, Nov. 11, Dec. 11.	
Milk Production, Disposition and Income 1972-73, by States.	April 22

Milk and Dairy Products Reports, continued

Dairy Products:

Production of butter, cheese, frozen products, evaporated, condensed and dry milk, and prices. Jan 30, Feb. 28, Mar. 29, Apr. 30, May 31, July 1, July 30, Aug. 30, Sept 30, Oct. 31, Nov. 29, Dec. 31. Monthly

Production of Manufactured Dairy Products, 1973 June 20

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AGRICULTURAL PRICES REPORTS  
(Released at 3:00 P.M.)

Agricultural Prices:

Prices received by farmers for principal crops and livestock products, Index Numbers of prices received by farmers, prices paid for production and family living items bought by farmers, Indexes of prices paid by farmers for articles bought and parity prices. Jan. 31, Feb. 28, Mar. 29, Apr. 30, May 31, June 28, July 31, Aug. 30, Sept. 30, Oct. 31, Nov. 29, Dec. 31. Monthly

Agricultural Prices -- Annual Summary of selected series for 1973, by States. June

Prices Received by Farmers for Manufacturing Grade Milk in Minnesota and Wisconsin, Annual Summary for 1973. July 31

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OTHER REPORTS  
(Released at 3.00 P. M.)

Farm Labor:

Family and hired employment on farms monthly, wage rates quarterly, beginning in January. Jan. 14, Feb. 8, Mar. 11, Apr. 12, May 8, June 10, July 12, Aug. 9, Sept. 10, Oct. 11, Nov. 8, Dec. 10. Annual Farm Labor, March, and Annual Average Wages, January. Monthly

Farms

Number of farms in operation and land in farms during 1973 and preliminary for 1974, by States. Jan. 4

Number of farms in operation and land in farms during 1974 and preliminary for 1975, by States. Dec. 30

Commercial Fertilizers -- Year ended June 30, 1973 (Final) May 7

Commercial Fertilizers -- By class. Year ended June 30, 1973. June 7

Commercial Fertilizers -- Year ended June 30, 1974 (Preliminary) Nov. 1

Commercial Fertilizers

Combined summary of available State Control officials published reports Jan. 29, Feb. 28, Mar. 29, April 30, May 31, June 28, July 31, Aug. 30, Sept. 30, Oct. 30, Nov. 29, Dec. 31. Monthly

Naval Stores:

Production and stocks of turpentine and rosin (wood and gum) and miscellaneous Naval Stores: Jan. 21, Feb. 20, Mar. 20, Apr. 19, May 21, June 20, July 19, Aug. 20, Sept. 23, Oct. 21, Nov. 20, and Dec. 20. Monthly

Annual production and distribution, consumption and stocks of turpentine and rosin and production and stocks of miscellaneous Naval Stores for the United States. May 16

Other Reports, continued

Cold Storage.

End of previous month cold storage commodity holdings of meats, dairy and poultry products, fruit and fruit products, and vegetables: Jan. 17, Feb. 19, Mar. 18, April 19, May 17, June 18, July 19, Aug. 19, Sept. 18, Oct. 17, Nov. 18, and Dec. 18. Monthly

Capacity of Refrigerated Warehouses.

March 1

Regional Cold Storage Holdings of meats, dairy and poultry products, fruit and fruit products, and vegetables for 1973.

March 22

Honey -- Annual Summary -- 1973:

Number of colonies of bees, honey and beewax production, prices and value 1973 and honey stocks December 15, 1973 by States. Jan. 15

Honey -- September 1974 Commercial Production:

Number of colonies of bees, yield per colony, and production, major States. Sept. 25

Mink:

Number of mink pelted and number of females bred, by color phases. May 10

\* \* \*

DAIRY REPORTS RELEASED AT MADISON, WISCONSIN at 9 00 A.M. CT

(To obtain copies contact

Statistical Reporting Service, 801 W. Badger Road, Madison, Wisconsin 53713)

Creamery Butter Production Tuesday of each week. 1/

Weekly

American Cheese Production Wednesday of each week. 1/

Weekly

Prices Received by Farmers for Manufacturing Grade Milk in Minnesota and Wisconsin: 2/  
Jan. 4, Feb. 5, Mar. 5, Apr. 5, May 3, June 5, July 5, Aug. 5, Sept. 5, Oct. 4, Nov. 5,  
and Dec. 5. Monthly

\* \* \*

BROILER HATCHERY REPORT RELEASED AT STATES CONCERNED, at 3:00 P.M.

(To obtain copies write to Crop Reporting Board, SRS, USDA, Washington, D. C. 20250 and request State reports desired.)

Broiler Hatchery Report:

Number of broiler chicks placed and broiler type eggs set for the previous week, 21 States. Released at 3:00 P.M. (Eastern time) on Wednesday. 1/ Weekly

\* \* \*

1/ Unless holidays conflict, in which case release is on the next business day.

2/ Reports on May 3 and November 5 released at 1 00 P.M. CT.

TURKEY HATCHERY REPORT RELEASED AT STATES CONCERNED, at 3.00 P.M.  
(To obtain copies write to Crop Reporting Board, SRS, USDA, Washington, D C 20250  
and request State reports desired.)

Turkey Hatchery Report

Number of eggs set and poult's hatched previous week for 9 important producing States.  
(California, Iowa, Minnesota, Missouri, North Carolina, Ohio, Texas, Virginia  
and Wisconsin.) Released at 3:00 P.M. (Eastern time) on Thursday of each week. 1/

Weekly

\* \* \*

TOMATO REPORT RELEASED AT ORLANDO, FLORIDA  
(To obtain copies contact Statistical Reporting Service Office,  
1222 Woodward Street, Orlando, Florida 32803 )

Tomatoes:

Plantings and rate of harvest, Florida. Released each Tuesday 1/ during planting  
and harvest season at 3.00 P.M.

Weekly

\* \* \* \* \*

1/ Unless holidays conflict, in which case release is on the next business day.

# CORN ACREAGE AND PRODUCTION

1972 and 1973

112

I Crop and Livestock  
O Reporting Service  
W 515-284-4340  
A April 1974

Estimates of Iowa corn acreage and production given here are prepared by the Iowa Crop and Livestock Reporting Service. County estimates for 1972 are based largely on data obtained from the 1972 Annual Iowa Farm Census. Estimates for 1973 are preliminary and based on survey and ASCS data. They are subject to revision on the basis of additional information from the 1973 Annual Iowa Farm Census and other available check data.

## IOWA CORN ACREAGE, YIELD AND PRODUCTION - 1972 and 1973

County and District	1972				1973 (Preliminary)			
	Acres Planted for all Purposes	Acres Harvested for Grain	Yield per Acre	Production	Acres Planted for all Purposes	Acres Harvested for Grain	Yield per Acre	Production
	Acres	Acres	Bushels		Acres	Acres	Bushels	
Buena Vista	146,800	139,200	120.0	16,709,000	150,200	141,400	113.6	16,060,000
Cherokee	139,700	129,000	117.8	15,199,000	146,300	136,800	113.6	15,538,000
Clay	132,100	122,900	118.2	14,530,000	139,600	130,500	106.3	13,875,000
Dickinson	87,900	77,000	110.5	8,507,000	90,300	81,400	108.4	8,825,000
Emmet	99,300	86,900	116.8	10,148,000	103,300	95,600	112.5	10,759,000
Lyon	157,100	139,100	110.8	15,438,000	164,000	153,400	103.3	15,839,000
O'Brien	147,100	137,600	122.4	16,839,000	150,300	142,500	118.0	16,816,000
Osceola	101,400	92,200	119.6	11,027,000	107,100	99,200	106.4	10,551,000
Palo Alto	133,400	126,000	116.9	14,728,000	140,600	131,500	115.7	15,208,000
Plymouth	226,000	218,500	111.9	24,448,000	239,200	222,700	103.3	22,995,000
Pocahontas	125,800	125,900	122.0	15,363,000	145,900	135,500	119.8	16,230,000
Sioux	243,400	204,700	110.4	22,595,000	257,200	239,500	106.4	25,472,000
NW District	1,750,000	1,599,000	116.0	185,510,000	1,834,000	1,710,000	110.0	188,168,000
Butler	134,500	129,300	112.8	14,580,000	138,000	133,000	103.3	13,733,000
Cerro Gordo	130,900	123,200	115.2	14,195,000	136,500	127,600	116.4	14,098,000
Floyd	106,600	104,000	114.5	11,906,000	114,000			
Klin	140,500	133,000	121.8	16,204,000				
Howe	131,500	127,700	124.0			81,600	112.5	15,036,000
Winnesh	107,200	100,000			114,400	105,100	103.3	8,426,000
NE District			109.8	123,007,000	1,247,000	1,150,000	108.4	11,395,000
							105.5	121,315,000
Audubon	102,100	92,600	109.2	10,112,000	107,000	100,200	102.2	10,243,000
Calhoun	129,800	127,600	126.0	16,083,000	137,600	129,900	108.4	14,084,000
Carroll	153,800	132,700	116.8	15,500,000	165,600	155,000	104.3	16,165,000
Crawford	154,800	152,900	106.9	16,343,000	170,000	160,100	103.3	16,531,000
Greene	136,000	130,600	131.1	17,116,000	142,300	134,300	119.8	16,086,000
Guthrie	92,400	88,600	112.4	9,956,000	99,800	93,400	103.3	9,644,000
Harrison	150,200	149,600	114.2	17,083,000	166,700	156,000	103.3	16,108,000
Ida	111,800	107,200	117.0	12,546,000	120,100	112,400	100.2	11,258,000
Monona	154,300	148,800	113.0	16,815,000	180,000	165,600	105.3	17,441,000
Sac	155,100	134,900	115.7	15,614,000	164,900	152,500	107.4	16,376,000
Shelby	150,900	145,800	116.5	16,987,000	162,000	150,800	106.4	16,038,000
Woodbury	203,800	186,700	112.7	21,038,000	225,000	209,800	99.1	20,797,000
W. C. District	1,695,000	1,598,000	115.9	185,193,000	1,841,000	1,720,000	105.1	180,771,000
Boone	126,500	126,000	134.7	16,969,000	132,000	128,600	122.9	15,801,000
Dallas	129,900	129,500	130.0	16,835,000	131,500	130,600	113.6	14,834,000
Grundy	130,300	126,100	125.0	15,762,000	136,200	133,100	113.6	15,118,000
Hamilton	140,100	138,800	127.2	17,658,000	148,000	144,400	112.5	16,252,000
Hardin	138,600	131,700	124.0	16,331,000	146,000	139,500	115.6	16,133,000
Jasper	146,400	140,400	120.5	16,919,000	152,500	147,700	116.7	17,233,000

U. S. Department of Agriculture  
Statistical Reporting Service

Iowa Department of Agriculture  
Agricultural Statistics Division



IOWA CORN ACREAGE, YIELD AND PRODUCTION - 1972 and 1973

County and District	1972				1973 (Preliminary)			
	Acres Planted for all Purposes	Acres Harvested for Grain	Yield per Acre	Production	Acres Planted for all Purposes	Acres Harvested for Grain	Yield per Acre	Production
	Acres		Bushels		Acres		Bushels	
Marshall	137,100	126,700	124.9	15,822,000	144,000	134,700	115.6	15,577,000
Polk	100,600	100,200	119.0	11,924,000	104,600	102,000	121.8	12,428,000
Poweshiek	99,400	95,000	114.0	10,830,000	105,000	100,400	106.3	10,670,000
Story	132,100	128,500	125.4	16,110,000	139,000	132,900	124.9	16,605,000
Tama	153,000	143,400	119.8	17,181,000	160,600	154,500	115.4	17,827,000
Webster	151,200	143,700	126.8	18,215,000	158,600	151,600	114.6	17,376,000
C. District	1,585,000	1,530,000	124.5	190,556,000	1,658,000	1,600,000	116.2	185,854,000
Benton	162,800	152,100	118.8	18,074,000	170,000	160,000	103.3	16,521,000
Cedar	139,500	126,700	119.1	15,090,000	145,000	136,600	108.9	14,873,000
Clinton	167,800	155,200	117.4	17,447,000	174,200	164,300	100.2	16,456,000
Iowa	104,400	101,200	111.1	11,248,000	110,300	104,800	104.3	10,930,000
Jackson	91,700	89,800	103.1	9,258,000	96,500	92,600	100.0	9,261,000
Johnson	112,000	104,200	113.0	11,779,000	116,500	110,400	103.3	11,399,000
Jones	119,700	111,400	113.0	12,590,000	124,000	115,700	102.2	11,827,000
Linn	146,400	132,000	115.2	15,210,000	152,500	142,600	100.9	14,387,000
Muscatine	78,500	78,200	115.8	9,054,000	84,000	80,000	107.8	8,624,000
Scott	107,200	105,200	115.6	12,163,000	112,000	107,000	109.7	11,738,000
E. C. District	1,230,000	1,156,000	114.1	131,913,000	1,285,000	1,214,000	103.8	126,016,000
Adair	90,500	83,500	109.0	9,104,000	93,200	90,200	107.4	9,686,000
Adams	61,500	57,400	105.9	6,078,000	63,300	61,600	109.5	6,745,000
Cass	124,000	117,000	109.9	12,855,000	127,500	123,100	105.3	12,965,000
Fremont	113,900	101,500	117.9	11,971,000	118,300	113,200	104.3	11,805,000
Mills	91,500	81,700	113.7	9,291,000	99,700	94,500	103.6	9,792,000
Montgomery	88,700	81,600	108.7	8,873,000	93,000	89,100	106.4	9,476,000
Page	96,400	92,800	111.0	10,301,000	104,000	99,600	109.0	10,856,000
Pott	225,700	209,300	115.1	24,099,000	238,000	224,200	104.3	23,381,000
Taylor	63,800	62,200	104.5	6,501,000	66,000	64,500	107.4	6,927,000
SW District	956,000	887,000	111.7	99,073,000	1,003,000	960,000	105.9	101,633,000
Appanoose	33,500	33,000	103.9	3,430,000	34,800	33,800	92.9	3,141,000
Clarke	34,800	33,700	103.9	3,502,000	36,900	34,600	99.0	3,425,000
Decatur	38,700	35,700	104.1	3,717,000	45,800	37,300	96.0	3,582,000
Lucas	39,500	36,800	103.1	3,793,000	44,600	38,000	99.1	3,767,000
Madison	72,000	71,300	112.7	8,034,000	77,000	72,300	103.3	7,465,000
Marion	79,900	76,300	114.1	8,703,000	84,800	77,300	106.4	8,221,000
Monroe	32,800	28,800	103.6	2,985,000	33,200	30,000	94.0	2,819,000
Ringgold	52,400	51,100	103.6	5,296,000	54,300	52,200	106.1	5,540,000
Union	47,600	46,400	102.3	4,749,000	49,400	47,000	102.2	4,805,000
Warren	74,000	73,700	118.3	8,716,000	76,500	74,800	102.2	7,646,000
Wayne	54,800	51,200	108.9	5,578,000	56,700	52,700	92.9	4,897,000
S. C. District	560,000	538,000	108.7	58,503,000	594,000	550,000	100.6	55,308,000
Davis	43,500	40,500	106.4	4,308,000	48,000	43,000	100.2	4,310,000
Des Moines	71,100	69,600	130.2	9,064,000	73,000	70,600	114.6	8,092,000
Henry	82,100	80,500	122.3	9,847,000	84,200	81,800	103.3	8,446,000
Jefferson	62,300	57,100	113.5	6,480,000	63,300	59,000	103.3	6,092,000
Keokuk	101,100	99,800	118.5	11,827,000	103,100	100,900	105.3	10,627,000
Lea	89,600	87,900	116.2	10,215,000	90,000	88,400	108.4	9,584,000
Louisa	76,000	74,100	124.2	9,202,000	77,000	75,800	110.5	8,375,000
Mahaska	108,800	103,000	116.1	11,960,000	111,000	106,000	107.4	11,383,000
Van Buren	48,000	44,200	106.4	4,704,000	49,000	46,000	99.1	4,560,000
Wapello	50,400	48,500	116.5	5,650,000	52,000	49,900	98.2	4,900,000
Washington	115,100	112,800	118.6	13,377,000	117,400	114,600	105.3	12,070,000
SE District	848,000	818,000	118.1	96,634,000	868,000	836,000	105.8	88,439,000
State	11,255,000		116.0		11,800,000		108.0	
		10,600,000		1,229,600,000		11,150,000		1,204,200,000

**APPENDIX E**  
**RANGELAND MANAGEMENT MISSION**

## APPENDIX E

### RANGELAND MANAGEMENT MISSION

#### E.1 INTRODUCTION & SUMMARY

Rangeland can be defined as land in large areas that supports vegetation suitable for livestock grazing. Rangeland is primarily a component of ranching and thus can be distinguished from pasture land which is organized into comparatively small parcels and is a component of farming operations. The range is managed predominantly by the manipulation of grazing stock, while pastures are much more intensively managed through seeding, fertilization, cultivation, and irrigation practices. The applications of remote sensing discussed in this mission are formulated to influence the management of rangeland in the U.S.

Although each state contains some rangeland, the Western States dominate. The majority of U.S. rangeland (total 1.2 billion acres) is owned or controlled by the private sector. The Federal Government, through branches such as the Forest Service, Bureau of Land Management, and Bureau of Indian Affairs, maintains jurisdiction over 31% (373 million acres), while private owners control 69% (829 million acres). Perhaps an even more significant figure is that 84% of the Animal Unit Months (AUM - amount of forage required to feed one grazing animal for one month) produced in the U.S. are produced by the private sector. The application of remote sensing to provide better range information, particularly to this private sector, is the emphasis of this mission.

### E.1.1 ERS APPLICATIONS IN RANGELAND MANAGEMENT

Improvements in the information available to the ranch manager for critical decisions would result in substantial benefits. Such improvements require the use of improved technologies for more efficient methods of acquiring, interpreting and distributing data. Remotely sensed earth resources data and associated analysis techniques can provide the new perspective needed to positively influence ranch management decisions. Rangeland characteristics, policies, and associated decisions can be stratified into three levels: long, intermediate, and short term.

#### E.1.1.1 Long Term (Range Resource Surveys)

ERS derived rangeland inventories could be the basis for long-term policy decisions on range resources, e.g., which lands are to be intensively managed for livestock and which are to be withdrawn from grazing for protection of a watershed. Major range inventories are presently conducted by the Federal Government. Range inventories by the Bureau of Land Management (BLM, DOI) and Forest Service (USFS, USDA) conducted every three to ten years, are designed for use in administering grazing allotments and other federal rangeland policies. As requested by the individual rancher, the Soil Conservation Service (SCS) inventories private rangelands. In addition to individual range site surveys, the SCS compiles private range acreage, county-by-county, in the Conservation Needs Inventory (CNI). Federal agencies plan for inventories once every five years, but because of manpower and budget constraints, this frequency is rarely achieved. Though detailed sampling strategies of biomass, soils, vegetation types, and other parameters are carried out in some federal inventories, the majority of the reports are based on the subjective

judgment of the observer looking over or driving by a parcel of land.

#### E.1.1.2 Intermediate Term (Improvements in Range Productivity)

The ERS system could contribute to the information needs of the rangeland manager involved in the continuing process of productivity improvement through more efficient investment of land, labor, and capital. Maintaining or improving range productivity requires periodic monitoring of the condition of range resources and the impact of management practices on their condition.

Current rangeland monitoring is a by-product of federal inventory activities. Although complete federal inventories may be published only every three to ten years, they are conducted over specific portions of U.S. rangelands each year. In addition, a rancher often monitors critical points on his own range. This monitoring activity allows him to assess the trends in range condition and patterns of forage utilization. However, cause-effect relationships of these trends in range condition often go unnoticed, and patterns of forage utilization are often only estimated visually.

#### E.1.1.3 Short Term (Livestock Inventory Adjustments)

Range feed conditions are the basis for major operational decisions regarding the number of livestock put on the range, when to remove them, when to rotate them, how many to remove, and when to provide supplemental feeding.

Currently, each rancher depends on his own experience and his own spot survey of critical areas of the range to assess range feed conditions.

Normally his critical decision period occurs on a monthly basis in conjunction with stock auctions which are held at several locations within each state. Some ranchers report their findings each month to the USDA Statistical Reporting Service (SRS). Rancher inputs are compiled into monthly range feed and condition reports on the local and national levels. Typically, the results are released as much as a month after the conditions were reported. They lack the timeliness and details needed by the rancher for livestock inventory decisions.

The manipulation of livestock inventories is the means by which the rancher converts range forage into animal units, and thus is the key to his profits. Rangeland is most efficiently utilized when a rancher succeeds in grazing the maximum number of head on a range without overgrazing the range. Overgrazing will severely damage the regenerative capabilities of the range and can permanently damage the productivity of land, which severely impacts both the rancher and the environment. At present most ranch managers must be conservative in their stocking decision. Due to the lack of sufficient timely information on range conditions, the manager usually intentionally undergrazes the range to account for the probable error in his estimate of range carrying capacity. In other words, the rancher would rather be safe than sorry. Since the range is often undergrazed and occasionally carelessly overgrazed, the rancher is obviously not utilizing the full potential of the range, and is not achieving maximum profits. Any improvement in range survey that would influence these short term management decisions would result in substantial benefits, not only on the short term but also extrapolated to the intermediate and long term.

### E.1.2 TOSS RANGELAND MISSION

This rangeland mission of TOSS is specifically designed to present a remote sensing information flow which will improve the capability for the ranch manager to maximize his profits through improved decisions at critical decision periods. Providing data to the ranch manager will incorporate Earth Resources Survey, ERS, data collection by a government agency, but specialized analysis to meet the needs of the individual rancher will be conducted by private subscription services. Analysis will be performed on a ranch by ranch basis incorporating survey rather than sampling techniques. The final products will include range condition reports and management guidelines supplied to the individual ranchers.

Though this mission does not discuss any medium or long term benefits in any detail, they are apparent. Compilation of monthly ranch survey results on a yearly basis would provide sufficient data to satisfy many of the intermediate term requirements. The longer term large area inventory could utilize the satellite data files or subscription service reports to feed a sampling plan for periodically determining total U.S. rangeland status.

### E.2 RANGE BIOMASS

Livestock grazing is the tool which converts the forage resource into economic value. Thus, the rangeland manager must make decisions which maximize forage yields while protecting the range environment. The efficient management of livestock grazing and stocking results in benefits to the rancher through increased earnings.

### E.2.1 RANCHER NEEDS

The major information needs for range management are the timely assessments and forecasts of range forage conditions. At present, ranchers obtain forage condition assessments from their own observations and from published maps and statistics of the USDA. Real time assessments are generally based on the growth of indicator plants coupled with the disciplined intuition of the rancher. However, forecasts are more difficult since the range condition is dependent on many variables including vegetation type, soils, previous usage, current stocking rates, and climatic factors. The existing methods of assessment and forecasts lack the timeliness and extent to maximize rancher earnings through proper utilization of available forage.

Remote sensing could provide more timely, accurate, and comprehensive forage information to the livestock manager, and could potentially lead to more dependable forage predictions. By using this improved information, more optimal decisions at critical decision periods could result.

### E.2.2 RANGELAND SPECTRAL RELATIONSHIPS

Colwell<sup>1</sup> presents a fairly comprehensive analysis of the factors involved in determining biomass via remote sensing techniques. The primary aim of the study was to reveal the effects of numerous variables including: soil reflectance, canopy structure, vegetation reflectance and transmittance, angle of incidence of radiation, angle and azimuth of observation, leaf area index, canopy height, percent vegetation cover, and standing

<sup>1</sup>John E. Colwell, Bidirectional Spectral Reflectance of Grass Canopies for Determination of Above Ground Standing Biomass. (PhD Dissertation, University of Michigan, Department of Forestry, 1973)



biomass. The conclusions of the study present a summary of the predominant biomass-multispectral relationships for any one point in time:

- (1) ● The reflectance of an all green canopy is largely due to the percent vegetation cover which, in turn, may be a reliable indicator of amount of biomass.
  - The relationship between % cover and biomass (canopy reflectance and biomass) is a function of the canopy structure. Thus, two vegetation associations with identical values of hemispherical reflectance and transmittance but different structural configuration will have a different relationship between canopy reflectance and biomass.
- (2) ● Depending upon the reflectance contrast between vegetation and soil, the red spectral region often possesses the greatest sensitivity to changes in per cent cover and biomass for all-green canopies at low to intermediate values of percent cover.
  - The IR spectral region generally possesses the greatest sensitivity to changes in percent cover and biomass at high values of percent cover.
- (3) The relationship between canopy reflectance and biomass is generally curvilinear for the full range of biomass.
- (4) ● Variation in soil reflectance can cause large variations in canopy reflectance at low values of biomass, thus making it difficult to establish a relationship between reflectance in single spectral band and biomass.
  - The IR/red reflectance ratio is effective in normalizing the effect of soil reflectance, including leaf litter, in a canopy.
  - The ratio is less effective at normalizing the effect of amount of shadow and standing dead vegetation.
- (5) ● The red reflectance varies the most with vegetation maturity (if senescence is included), so at times it is a very poor indicator of standing biomass (total, or green or brown fraction).
  - The IR reflectance varies the least with maturity, so it may be the best "all season" spectral region for determining biomass.

- (6) Small zenith angles are best for determining a large range of values of percent cover and biomass.
- (7)
  - Reflectance at a look angle other than the vertical is a complicated function of the look angle and azimuth, and different spectral bands may have different trends.
  - Certain ratios (such as IR/red), may actually worsen angular effects rather than alleviate them, under certain conditions.
  - At increasing look angle, the range of values of percent cover and biomass to which canopy reflectance is sensitive is decreased.<sup>1</sup>

Colwell's findings, though qualified by the condition and vegetation types analyzed in his study, can be considered generally applicable since they were modeled from fundamental principles.

A few investigators utilized aircraft and Landsat multispectral data and imagery to achieve biomass estimates of rangeland. Their results are generally consistent with the Colwell summary.

#### E.2.3 CASE STUDIES OF BIOMASS ESTIMATES USING LANDSAT DATA

Landsat certainly provides the platform which can investigate the feasibility of biomass estimates via remote sensing. Indeed, results from investigators have demonstrated that multispectral digital analysis of Landsat data can provide accurate biomass assessment.

The primary investigators include Rouse (Texas A&M University), Carneggie (University of California, Berkeley), and Seevers (University of Nebraska).

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<sup>1</sup>John E. Colwell, Bidirectional Spectral Reflectance of Grass Canopies for Determination of Above Ground Standing Biomass

Rouse, et al<sup>2</sup>, conducted an extensive investigation of rangeland within the Great Plains Corridor extending from Southern Texas to North Dakota. The study emphasized monitoring the green wave effect of natural vegetation and developing techniques for quantitative measurement of vegetation conditions, including a green biomass estimate.

In order to assess the available forage, a model was first developed to measure relative greenness of range vegetation. It was known that Landsat band 5 (.6 - .7  $\mu\text{m}$ ) energy is strongly absorbed by chlorophyll and Landsat bands 6 & 7 (.7 - 1.1  $\mu\text{m}$ ) energy was reflected by green vegetation. Therefore, a ratio of red to near infrared bands should provide a reliable index of green biomass. In order to normalize the simple red/IR ratio, Rouse devised a transformed vegetation index (TVI) which was most effective when bands 5 and 6 were used in the form

$$\text{TVI } 6 = \sqrt{\frac{\text{Band } 6 - \text{Band } 5}{\text{Band } 6 + \text{Band } 5} + 0.5}$$

The correlations of the TVI with ground truth measurements, including total standing biomass, moisture content of the vegetation, and percentage green vegetation on a dry weight basis, were conducted for eleven test sites. The results indicated that for typical mixed prairie grassland vegetation, a reliable determination of the time of initiation of spring green-up is possible. Broad increments of green biomass can be estimated, which enables quantitative monitoring of herbage production increases in the spring and early summer. However, accurate green

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<sup>2</sup>J. W. Rouse, et al, Monitoring the Vernal Advancement and Retrogradation (Greenwave Effect) of Natural Vegetation (Final Report NASA Contract No. 5-21857, Nov. 1974).

biomass estimation and vegetation condition monitoring must involve the use of regression models developed for specific vegetation/soil types.

In order to evaluate the feasibility of this area modeling of biomass relationship, the Throckmorton data set (2 annual cycles) was selected. Regression between TVI6 and percentage plant moisture content, and TVI6 and green biomass were modified by an input model which contained pertinent weather information. The best model included climatic variables: precipitation since last overpass, amount of precipitation on the day before the overpass and maximum temperature on the day of overpass. A multiple regression analysis was performed using TVI6 and these weather parameters to estimate green biomass for Throckmorton. The model demonstrated the ability to estimate green biomass in increments of 250 to 300 kg/ha with a 95% probability from TVI6 data and readily available weather data. Rouse, et al, believe the relationships tested at Throckmorton indicate that a very practical working model can be developed for estimating green biomass from Landsat type data and weather data.

Carnegie, et al<sup>3</sup>, used a multistage sampling and analysis plan to assess range conditions in the California annual grasslands. In this study, Landsat imagery and CCTs were analyzed to determine their utility in monitoring and assessing range conditions, forage growth stage, and relative forage production.

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<sup>3</sup>D. M. Carnegie, S. D. Degloria, and R. N. Colwell, Usefulness of ERTS-1 and Supporting Aircraft Data for Monitoring Plant Development and Range Conditions in California Annual Grasslands (Final Report BLM Contract No. 53500-CT3-266(N), March 31, 1974)

Spectral radiance data from specific MSS bands and ratios of selected bands appear to provide accurate indicators of germination, peak of green foliage development, and the drying period. The timing of these phenological events would be appropriate for inputs into empirical range models. The authors determined that the peak green foliage production period is signalled by the peak of the spectral reflectance curve of MSS bands 6 and 7. The range condition when approximately half of the range sites are dry and the other half mature but green is signalled by the crossover of MSS bands 4 and 5.

This type of multispectral radiance data, which provides quantitative verification of the occurrence of critical growth stages, and relative differences in forage production between range sites, combined with supplemental data such as ground sampling for forage production, climatic data, and ground spectral reflectance measurements, can be incorporated into simple statistical models to predict expected forage production.

One approach to a simple model for estimating forage production would be a multiple regression equation model wherein the dependent variable, forage production, is a function of the independent variables, Landsat spectral radiance data ratios Band 7/5, ground measured spectral radiance data, ground sampled forage production, and climatic data. Variations of this model would be necessary depending upon whether the estimated forage production was the amount of standing forage available to livestock at a given time, or the amount of forage which could be produced under the climatic regime and the degree of utilization of a particular rangeland.

A second approach for estimating forage production would be required when the estimate was concerned with the extent to which forage production in any given year was greater than or less than the expected average forage production. Again, a multiple regression model would be in order but the dependent variable would be the expected surplus or deficit of forage predicted for a given year, which would be a function of the deviation of spectral reflectance, deviation of ground sampled forage production from the average, and deviation of expected climatic regime, namely, amount and distribution of rainfall and temperature.

In conclusion, Carneggie, et al, indicate that when Landsat spectral radiance data is extracted from specific range sites, one can determine quantitatively the occurrence of germination, the peak of foliage production, and the period of drying from spectral curves constructed from a sequence of Landsat images. In addition, ratios of spectral bands, namely, 7 over 5, provide a sensitive indicator of changes in growth stages and an indication of the relative differences in forage production when two or more range areas are compared.

Seevers, et al<sup>4</sup>, conducted an investigation of rangeland over the Sandhills region of Nebraska. Eilian sands composing the soils of this area are relatively uniform, thus minimizing the differences in radiance due to soil variability. In addition, the type of vegetation is predominantly a uniform cover of short mid-grasses. Spectral variations throughout the 52,000 km<sup>2</sup> region are, therefore, primarily a function of the amount of vegetation covering the soils and are influenced by few other variables.

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<sup>4</sup>P. M. Seevers, J. Drew, and M. P. Carlson, Vegetative Biomass Estimations from Landsat-1 (NASA Earth Resources Survey Symposium, June 1975).

Under these conditions, Seevers obtained correlations of MSS band 5 radiance values to vegetative biomass. Correlation coefficients for radiance values obtained from CCTs averaged about .90. These relationships between band 5 and vegetative biomass applied to sites subjected to livestock grazing as well as sites that were not grazed. The cattle carrying capacity variations over the region where the correlations applied also varied from 1 acre/AUM to 10 acres/AUM. These single band correlations may only be applicable under similarly ideal conditions, but the correlations do exist and are a real example of biomass extraction capabilities.

Each of these three studies demonstrates a different technique and each has been successful over the specific region where it was tested. The results indicate the extraction of biomass is possible using multispectral satellite data, but that the relationships are quite variable and must be derived for specific areas. The result of the biomass estimates should be in terms of usable forage per unit area. Satellite data could provide a viable alternative for estimating biomass, and thus could be extremely beneficial to the range manager.

### E.3 CLOUD COVER IMPACT ON RANGELAND MISSION

Cloud cover analysis for the U.S. rangeland mission is centered upon the statistics available for the western states. The vast majority of rangeland exists in Washington, Oregon, California, Idaho, Nevada, Arizona, Utah, Montana, Wyoming, Colorado, New Mexico, North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas. Obviously the climatic conditions and probable cloud cover vary considerably over this large area.

### E.3.1 TOTAL FRAME

Five homogeneous cloud cover regions<sup>1</sup> are represented over the above western rangelands. These regions are outlined in Figure E-1. For the cloud cover impact analysis, Landsat size frames and Landsat FOV will be assumed. The cloud cover statistics expressed are for 100 x 100mm frames, not for individual ranches or sampling units within the frame. For optimum utilization of the total image and for efficiency in automatic data analysis, a scene should contain cloud cover of 30% or less of the total image. For actual model utilization, any cloud-free area could be analyzed and the results extrapolated to predict range conditions on the cloud covered area. This approach would not be hindered by cloud cover totals as long as some cloud-free area exists. However, the efficiency of automatic analysis would probably decrease as total cloud cover increases, especially under convective cloudiness conditions where one would need to look through holes in clouds. Synoptic cloud masses that completely cover a portion of the image but do not influence the remainder of the image would provide less of a problem. In general, the fewer the clouds the more efficient the analysis. The selected value of  $\leq 30\%$  does provide a reasonable baseline for cloud cover considerations.

The general homogeneous cloud cover description and mean cloud cover statistics for the five regions are given in Tables E-1 and E-2. In all rangelands except for the western slope rangelands of California, the growing season generally extends from April, May - September, October. The daytime mean cloud cover for most regions is relatively lower through

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<sup>1</sup>Sherr, P. E., et al, "World Wide Cloud Cover Distribution for Use in Computer Situations," Allied Research Associates, NAS 8-21040, June 1968.



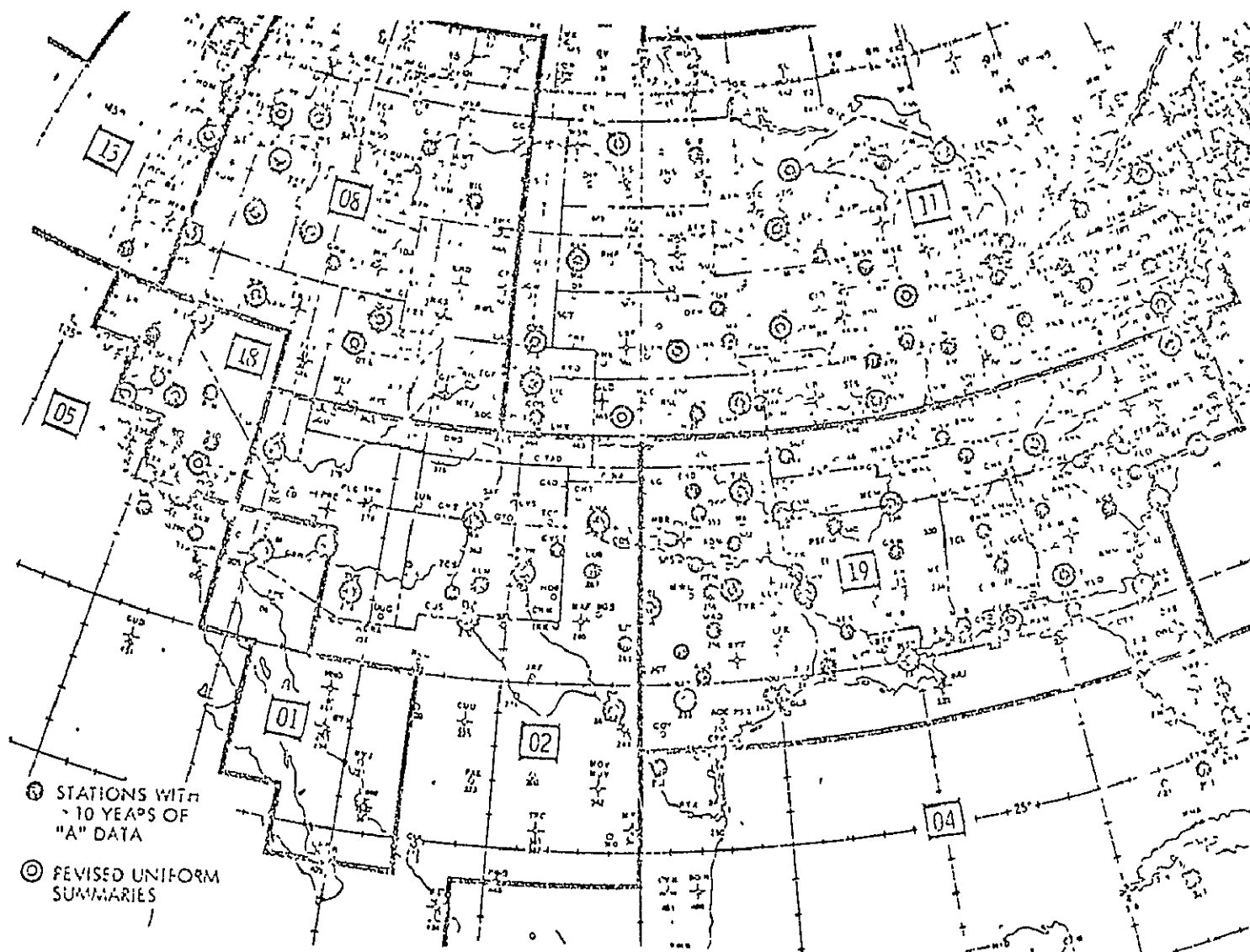


Figure E-1. Cloud Cover Regions of the United States Source: ERTS Cloud Cover Study, North American Rockwell, NAS 5-11231; March, 1971

Table E-1. General Description of Climatological Regions

Region Number	General Description	Location	Seasonal Change in Cloud Amount	Mean Monthly Cld. Amt. June-August in %	Mean Monthly Cld. Amt. Dec-Mar in %	Predominate Cloud Type	Diurnal Variation In Cloud Amt.	Hour Of Maximum Cloud Amt. Local Time
2	Little Cloudiness	Sub-Desert Areas	Small	< 40	< 40	-	Small	-
8	Mid-Latitude Clear Summer	North America	Extreme	< 40	~ 70	Synoptic Scale	Small	-
11	Mid-Latitude Land	Northern Hemisphere	Moderate	~ 50	~ 70	Synoptic Scale	Small	-
18	Mediterranean	Europe, Western, N. America	Extreme	~ 30	~ 60	Synoptic Scale	Small	-
19	Sub Tropic	Northern Hemis- sphere ~ 30°N	Moderate	< 50	~ 60	Convective Synoptic	Large Scale	1600 -

Table E-2. Mean Cloud Cover Values of U.S. Regions

Region/ Months	1000 LST/ 2200 LST	Daytime	Nighttime	All Hours (Mo )	All Hours (Season)	All Hours (Annual)
2 Jan	52.9/43.9	52.7	13.9	48.3	47.6	35.7
Apr	46.8/34.9	46.8	37.2	42.0	41.1	
July	13.1/10.2	13.2	12.6	12.9	16.7	
Oct	46.6/35.8	46.9	35.5	41.2	37.2	
Annual						
8 Jan	75.6/67.8	73.4	68.6	71.0	67.9	50.7
Apr	64.4/54.0	65.2	54.8	60.0	59.1	
Jul	25.6/26.1	25.1	25.1	26.6	33.4	
Oct	15.4/35.5	44.9	35.6	40.2	42.4	
Annual						
11 Jan	69.8/59.4	67.8	60.3	64.0	63.1	54.4
Apr	66.8/55.8	66.8	56.6	61.7	60.2	
July	57.1/38.1	56.8	42.3	49.5	49.1	
Oct	45.5/37.1	46.2	37.0	41.6	45.6	
Annual						
15 Jan	61.0/49.1	58.9	51.3	55.1	53.2	41.1
Apr	45.9/35.0	44.3	38.4	41.4	43.4	
Jul	23.0/24.2	24.3	30.8	27.6	30.6	
Oct	43.8/32.7	40.6	36.2	38.4	37.2	
Annual						
19 Jan	68.5/36.2	66.9	57.8	62.3	58.7	50.8
Apr	64.0/45.2	62.6	51.0	56.8	55.9	
Jul	52.5/36.9	54.1	39.7	46.9	45.3	
Oct	46.7/32.0	46.3	34.6	40.5	43.2	
Annual						

the growing season. This climatic condition increases the probability of obtaining cloud free or  $\leq 30\%$  cloud cover images in the range areas. To further illustrate this point, the frequency of clear skies is plotted in Table E-3 from April-October for the five regions.

Since a critical decision point in the range management models occurs on a monthly basis, it is necessary to insure with a reasonably high degree of probability that at least one image/month with cloud cover  $\leq 30\%$  will be available. To assess the ability to fulfill these requirements, two analyses will be considered. First, the probability of seeing 70% of the Landsat frame in N passes will be derived from the ERTS Cloud Cover Study of North American Rockwell. Secondly, Landsat success in imaging frames of  $\leq 30\%$  cloud cover from July '72 - July '74 will be considered.

#### E.3.1.1. ERTS Cloud Cover Study

Probabilities of seeing the Landsat frame were determined by a one-or-two look viewing mode. That is, the one-or-two look mode allows a selected percentage of an area to be seen (70%) in either a single look or in combining the amounts seen in each of two or more looks. Results represented in Table E-4 for April, July and October are probabilities of seeing 70% of the Landsat frame in 1, 2, 3, or 4 independent passes.

From this analysis the average probability of imaging 70% of the ground surface with only one pass equals 45.5%, with two passes 69.5%, with three passes 82.3%, and with four passes 89.2%. On a region by region basis the probability would be much higher for region 2 than for region 11. On a temporal basis the probability would also be much higher in July than in April. However, in developing a total survey routine, the combined

Table E-3. Relative Frequency of Clear Skys (1000 Local Time).

Region Month	2	8	11	18	19
APR	21%	19	11	23	14
MAY	30	14	12	20	10
JUNE	43	25	20	40	10
JULY	60	40	10	52	11
AUG	60	26	15	46	15
SEP	38	39	25	40	21
OCT	18	24	27	30	30

Table E-4. Probability of Seeing 70% of a 100 x 100 nmi Area in 1, 2, 3, or 4 Passes (1000 Local Time).

Region	Month	Passes			
		1	2	3	4
2	APR	46.7	73.1	86.9	93.8
	JUL	86.9	99.9	99.9	100
	OCT	39.5	67.6	83.7	92.2
8	APR	26.3	47.2	62.9	74.4
	JUL	70.3	92.9	98.4	95.7
	OCT	45.9	72.9	87.0	94.0
11	APR	22.8	41.8	56.8	68.4
	JUL	30.2	54.7	71.8	83.0
	OCT	47.0	73.5	87.3	94.0
18	APR	41.7	71.0	86.6	94.1
	JUL	71.8	93.8	98.8	99.0
	OCT	47.7	74.6	88.2	94.7
19	APR	26.7	47.4	62.9	74.2
	JUL	35.4	62.0	78.8	88.6
	OCT	43.0	69.7	84.5	92.3
AVE		45.5	69.5	82.3	89.2

case must be considered. This analysis would indicate that at least three passes/month would be necessary to provide reasonable reliability (82.3% chance) or seeing 70% of the surface within each 100 x 100 nmi. frame.

#### E.3.1.2 Landsat History of Coverage over the Western U. S.

The history of Landsat 1 coverage over the U. S. between launch in July, 1972 through July 1974 was analyzed to determine the probability of obtaining an image with 30% or less cloud cover. The percentages are for the entire two year period and are derived by simply dividing the total number of images with  $\leq 30\%$  cloud cover by the total number of Landsat passes (40). A plot of Landsat history in obtaining low cloud cover images in the western U. S. is represented as Figure E-2. A contour value of 50% indicated that 50% of the time Landsat passed over the area, an image with  $\leq 30\%$  cloud cover was obtained.

The Landsat history indicates that a majority of the Western U. S. has averaged 50% or greater imaging capability with 30% or less cloud cover. If these results could be extrapolated back to individual passes, for every two passes (36 days), at least one image with low cloud cover was obtained. This type of extrapolation is probably biased, but can serve as a rough estimate.

The range model is concerned with 30 day decision periods. However, since the passes are independent, there is probably no statistical advantage to two passes in 30 days or 36 days. There are areas within the western range where historical data indicates less than one 30% cloud cover image was obtained in every two passes. This coupled with the uncertainty of the distribution of the successful passes introduces a question as to

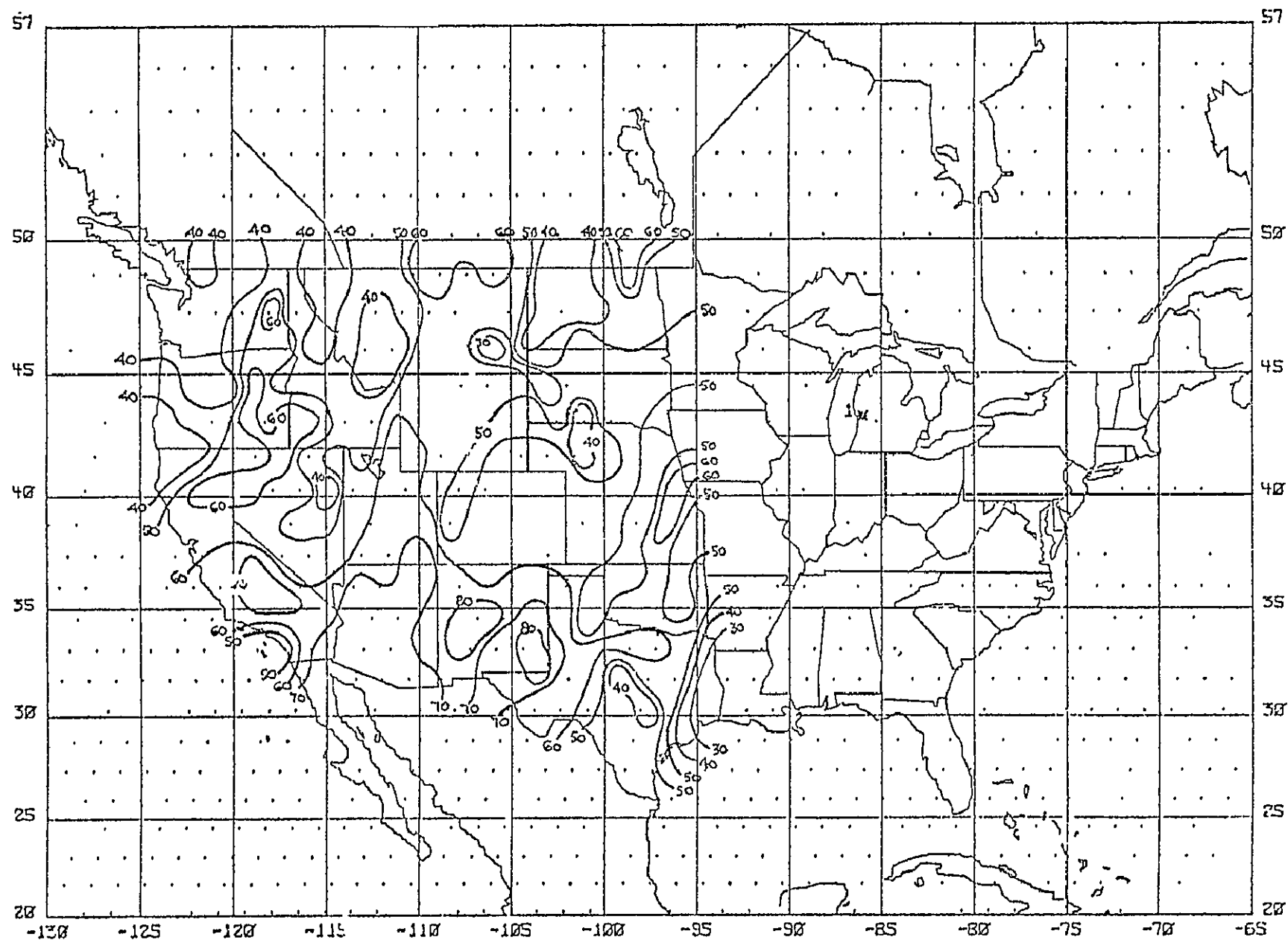


Figure E-2. Percentage of Landsat Passes with Cloud Cover  $\leq 30\%$  Western U. S. Range Lands  
July 72 - July 74

whether two passes per month would assure a  $\leq 30\%$  cloud cover wage. On the other hand, three passes/month would provide a reliable scheme for attaining an image with low cloud cover.

In summary, both the ERTS Cloud Cover Study and the Landsat historical analysis can justify coverage of three passes per month (ten day intervals) assuming a 100 x 100mm frame size.

#### E.3.2 INDIVIDUAL SUBSCRIBER RANCHES

Once a frame has been selected, using the 30% or less criteria, automatic analysis will be applied to survey each subscriber ranch within the frame. Cloud impacts on this survey will probably effect an all or nothing decision. If a ranch is partially cloud covered (including cloud shadows) it may not be efficient to analyze the ranch for inputs to the model. Though complicated data analysis procedures are possible, most statistics and model outputs will probably be based on total ranch averages. If the entire ranch cannot be surveyed, it will probably be beneficial to wait for clear data. Extrapolations on forage conditions over the ranch could be conducted from historical relationships with nearby subscriber ranches which are cloud-free.

The automatic analysis of Landsat data would thus be dependent on two subjective decisions of the data analysis cost benefits or efficiency. First, a large enough portion of the entire frame must be cloud-free to justify generation of computer compatible CCTs from HDDTs. Secondly, individual subscriber ranches must be totally cloud-free to allow for efficient analysis unless special ranch stratification capabilities are inherent in the survey procedure.



#### E.4 FUNCTIONAL IMPLEMENTATION CONCEPT

The benefits derived from a rangeland mission will be represented as increased profits to the individual rancher through increased production. In order to achieve these results, remotely sensed data analysis must be coupled with specific economic and climatic variables on a ranch by ranch basis. The functional implementation of this benefits concept involves the participation of both government services and private industry (Figure E-3).

A government agency or administration will be responsible for maintaining an operational series of satellites capable of providing earth resources data to fulfill acceptable spatial, spectral, and temporal criteria. In the U.S. Rangeland mission, adequate data must be available for preparation of monthly reports by the subscription service for delivery to ranch managers. Spatial and spectral coverage is dependent on the number of satellites, type of sensor, number of days between passes, and cloud cover. The mission design will incorporate these variables into a system which will provide the highest probability of attaining acceptable data within justifiable cost constraints. As the data is collected, criteria including cloud cover and the data demand on a frame by frame basis will be applied to deciding whether a Computer Compatible Tape (CCT) is to be generated. If the decision is yes, the raw satellite data will be pre-processed to output a standard CCT product. The CCT will then be sold to subscription services by the government on a standing order basis. The turnaround time from data collection to CCT delivery should not exceed five days. The Federal Government function is then complete. Federally sponsored rangeland surveys, conducted by the Bureau of Land Management,

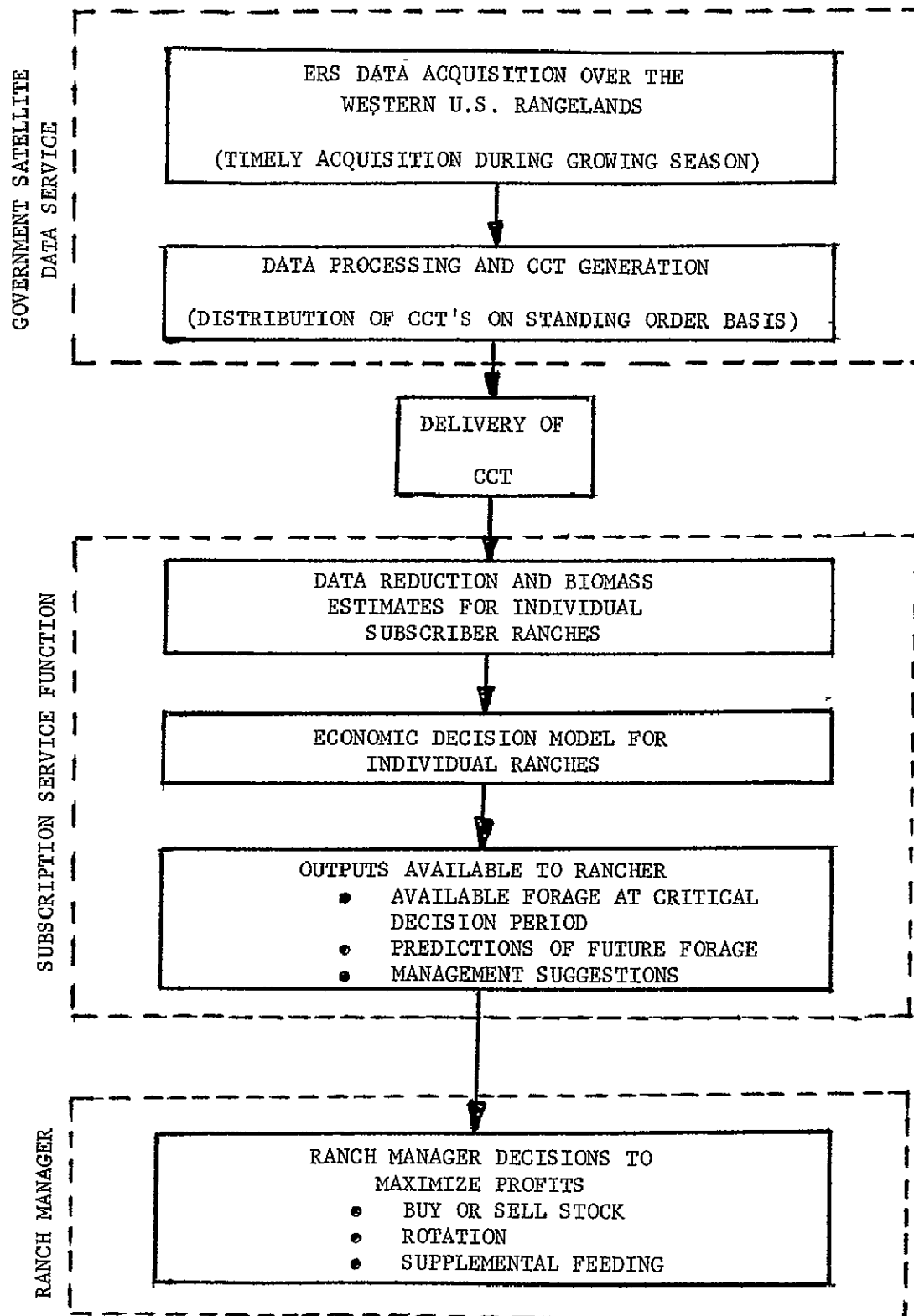


Figure E-3. Rangeland Functional Implementation Concept

Forest Service or other organization, will undoubtedly also use this data. However, these uses are not considered in the functional implementation of this mission.

The success of private subscription service depends on the quality and timeliness of information and services it can sell to the individual subscriber, rancher. The subscription service must place orders for all necessary satellite data as well as obtaining timely data on stock and feed prices, individual rancher stocking rates, ground truth for biomass correlations, weather data, and other parameters. All necessary information for each ranch must then be interpreted by automatic or interactive data processing through specific biological and economic models. The output products required will be defined by the individual subscriber and could include available forage at any one point in time, and/or predictions of available forage or stocking manipulation over a desired interval. An important qualification of any output will need to be a quantitative assessment of the estimate or prediction errors. Data analysis by the subscription service will become more efficient as the service gains customers from contiguous ranches. Surveys over larger portions of the ERS frame will allow for the derivation of pertinent relationships between terrain and vegetation differences, ranch to ranch management, and other factors which could improve the reliability of each monthly estimate. In any case, output products will need to be produced on a ranch by ranch basis.

The ultimate goal of the rangeland mission concept is to provide information to the ranch manager which will maximize profits. Effective use of rangeland resources depends largely upon well designed plans geared

to meet the ranch operators' goals. Each rancher must understand and be able to apply the subscription service products which are geared to his specific needs. Ranch decisions that will benefit from the monthly report will include buy and sell decisions, range readiness, stock rotation, and supplemental feeding. Better decisions will lead to a maximization of rancher production and profits.

#### E.5 MISSION REQUIREMENTS

Effective ranch management is dependent both upon having a satisfactory inventory of rangeland resources and knowing what economic tradeoffs are available. The rancher needs a variety of inputs to properly effect a decision. Remote sensing can provide certain important parameters, particularly concerning range feed conditions. These inputs, coupled with economic parameters, past practices, and climatic factors, can be modeled into helpful decision criteria.

During the growing season, range feed conditions are the basis for major decisions regarding the number of livestock to put on a range, when to rotate them, when and how many to remove, and when to provide supplemental feeding. Currently, the rancher depends on his own experience and his own spot survey of critical areas of his range to assess range feed conditions. Normally, the rancher's critical decision period occurs on a monthly basis. The USDA does compile and publish range feed and condition reports, but typically these reports are released as much as one month after the conditions are reported. Remote sensing could improve the timely assessment of range resources, provided a system is engineered which can fulfill the following specific requirements.

#### Report Cycle (Monthly)

Manipulation of livestock is the primary method of managing range.

This manipulation could include buying, selling, rotation, or supplemental feeding. The critical decision period for livestock manipulation occurs at the end of each month when livestock auctions occur at strategic locations within each state. Data on range forage and carrying capacity as well as economic factors are important at this decision period. Remote sensing can provide range biomass assessment with a high degree of accuracy as long as the data lag, time lag from data collection to subscription service report to the rancher, is on the order of one week. Survey errors increase as the data lag increases, unless properly compensated for by climatic conditions, or correlations exist between more recently surveyed areas and the particular area of interest. In general, the subscription service will be required to report to the rancher near the end of each month in order for the rancher to affect stocking decisions.

#### Timeliness (Approximately one week)

Forage conditions need only be measured once per month, near the end of the month. Survey data included in the subscription services monthly report should be not more than one week to nine days old unless proper compensations have been introduced to modify the forage estimate. Cloud cover is a major problem in producing timely assessment of forage conditions. More than one pass per month is required to provide a high probability of seeing the rangeland of interest. For example, a ranch might be cloud-free during the first pass of the month, but cloud covered for each of two successive passes. In order to make a reliable assessment of the conditions on the ranch, the analysis of forage from the first pass must be extrapolated using interim weather conditions, correlations with nearby

rangeland which was cloud-free on the most recent pass, or other compensating factors. The longer the time lag between the last survey of a ranch and the monthly reporting period the larger will be the potential errors.

#### System Accuracy - (90%)

A biomass (kg/ha.) assessment accuracy level of greater than 90% would appear to be an adequate baseline. The accuracies achieved by individual ranchers on their own land is difficult to determine. In general, substantial benefits would result if biomass could consistently be determined with a 90% accuracy.

#### Output Product (Forage Utilization and Prediction)

The output products provided by the subscription service to the ranch manager would vary with respect to rancher needs. Products would be in the form of maps or tables describing any or all of these biological or economic factors: forage (biomass weight per unit area), forage consumption (AUMs), prediction of available forage over a desired interval, stocking models. The rancher will use these products as inputs to his critical ranch management decisions.

#### Output Distribution (Reports to Ranch Manager by Subscription)

Subscription services would be responsible for the timely delivery of output products and services to the individual subscribers (ranch managers). In general, the report will be delivered prior to local stock auctions at the end of each month.

### Area of Coverage (U.S. Rangeland)

Although each state contains some rangeland, the western states dominate both in total rangeland area and in the proportion of total land in range Figure E-4. The western states include:

Arizona	Nebraska	South Dakota
California	Nevada	Texas
Colorado	New Mexico	Utah
Idaho	North Dakota	Washington
Kansas	Oklahoma	Wyoming
Montana	Oregon	

The majority of the U. S. range (total 1.2 billion acres) is owned or controlled by the private rancher. The Federal Government maintains jurisdiction of 31% of the rangeland (373 million acres), while non-federal owners control 69%, or 829 million acres. Perhaps an even more significant figure is that 84% of the Animal Unit Months (AUMs) are produced by the private rancher. The functional concept of this mission is designed primarily to serve the private ranch managers of the Western United States.

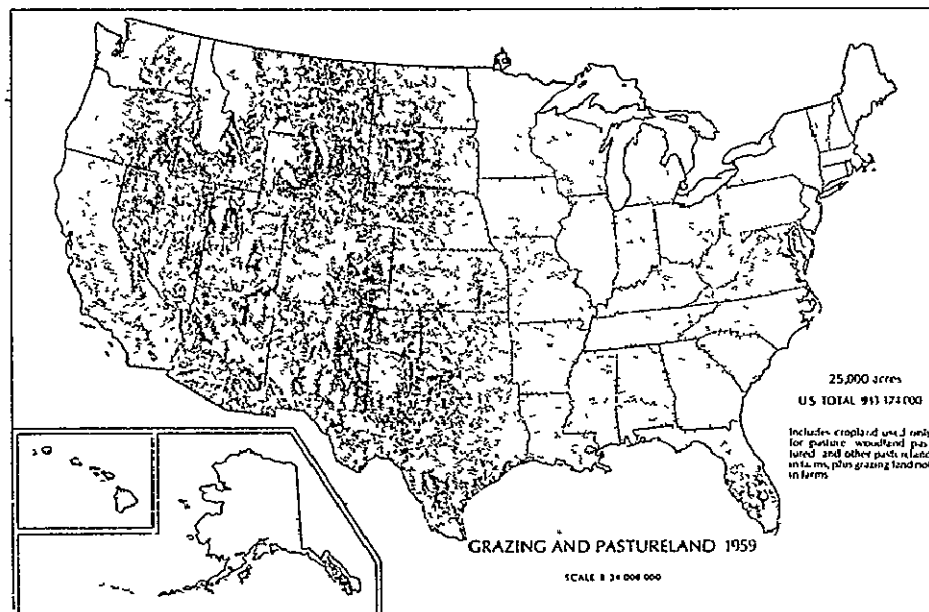


Figure E-4 Extent of Rangeland

### Grid Size (800a - 324 ha.)

The size of a ranch and the carrying capacity of rangeland vary from state to state and by economic class. Section E.7 presents the average ranch sizes in several states by state and by economic class. Depending on the orientation of the individual ranch with differences in rangeland type and biomass, the subscription service could provide average data for the entire ranch or offer separate reports for significantly different biomass strata of the ranch. On the average the grid size or size of strata reported by the subscription service would be greater than 800 acres. The rancher could therefore contract for individual reports on each 800 contiguous acre portion of his ranch, if desired. An example stratification of a 5,000 acre ranch containing four distinct range biomass strata is represented in Figure E-5. The subscription service could provide detailed information on each of the strata in this example.

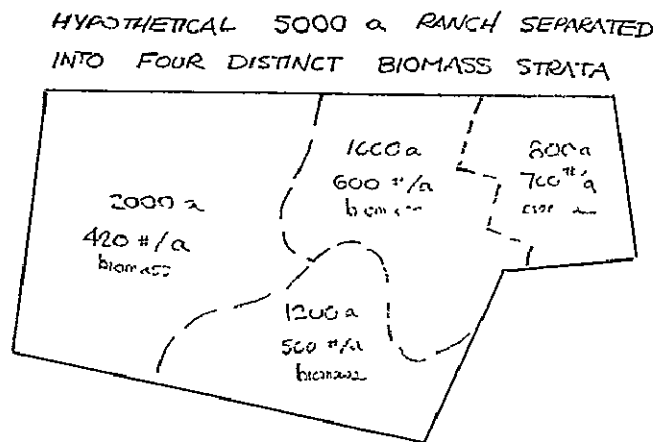


Figure E-5



## E.6 INFORMATION FLOW

The information flow incorporates the functions of three distinct groups:

(1) Federal Government - provides timely raw data, (2) subscription service - conducts data analysis and product generation for the rancher; (3) ranch manager - applies the derived information to maximize profit. Details of the information flow (Figure E-6) are explained in chronological order.

### (1) Earth Resources Satellite Data

Data will be collected over the U. S. rangelands. The coverage period selected will provide a reliable source of cloud free data during the rangeland growing seasons. Data will be transmitted in real time to ground receiving stations. Selected data will then be preprocessed and delivered to the subscription services by the ground stations or through some other data handling procedure which will insure timely delivery of a standardized computer compatible tape (CCT) to the subscription services. Orders will be filled from standing orders which will be controlled through a data base catalog.

### (2) Total Frame Cloud Cover Evaluation

Assuming CCTs will not be generated for every frame regardless of cloud cover, decision criteria, primarily based on costs, will have to be devised for maximum acceptable frame cloud cover necessary for CCT generation. There are a variety of ways to effect a decision at this point including: making CCTs for frame subsections, only making a CCT for total frames  $\leq 30\%$  cloud cover, or make a CCT regardless of cloud cover. Cloud cover decisions could be performed automatically or through an interactive technique. Cloud cover impacts are discussed in more detail in Section E.3.

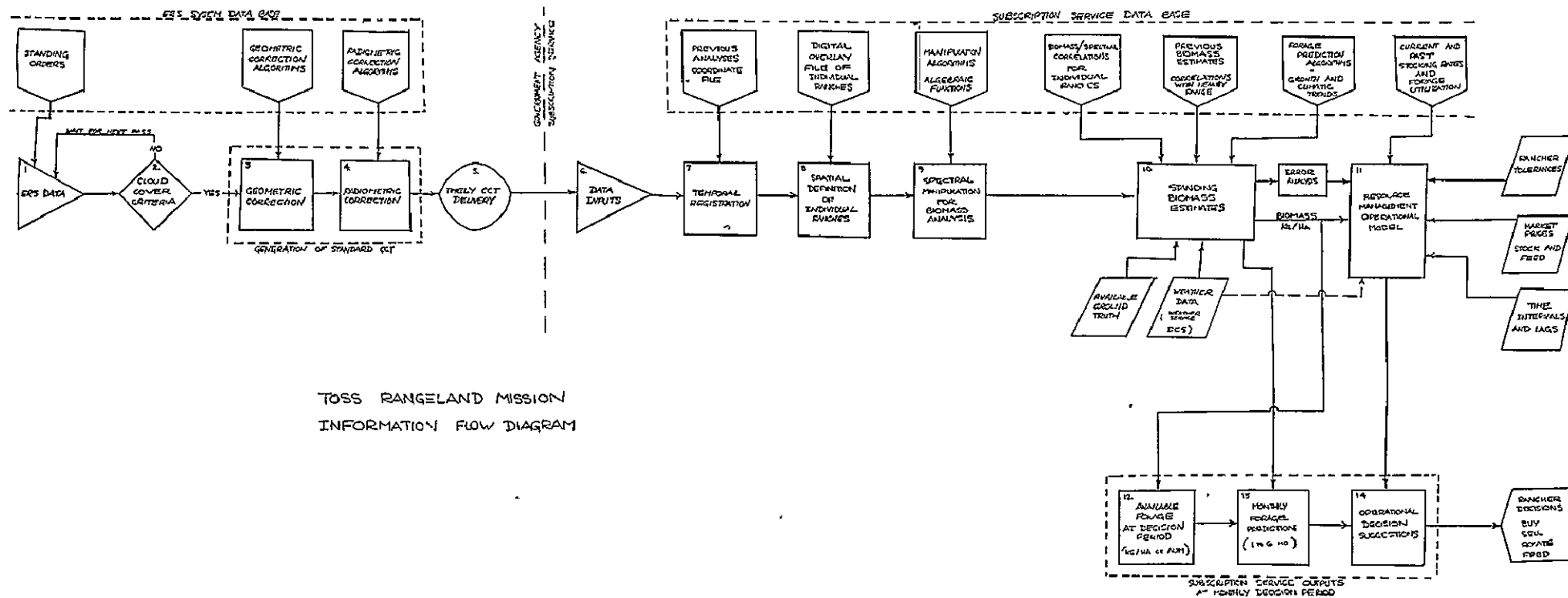


Figure E-6. RANGELAND INFORMATION FLOW

### (3) - (4) Generation of CCT

Once a frame or portion thereof is selected for eventual delivery to the subscription service, a standardized CCT will be generated. The raw data will be organized into a standard format and be geometrically and radiometrically corrected and calibrated. The objective of the standardization is simply to provide meaningful data that can be utilized efficiently by the subscription service without additional time consuming and costly preprocessing.

### (5) Timely CCT Delivery to Subscription Service

Delivery to the subscription service should be achieved in 3 to 5 days from data collection. It is beneficial to keep the total data turnaround time to a minimum. With the delivery of the CCT, the direct Federal Government function in the total information flow is complete.

### (6) Input Data for Area of Interest to Subscription Service Analysis System

Digital data must first be input to the interactive or automatic analysis system, where portions of the total frame that include subscriber ranches are selected for detailed analysis. Interactive analysis techniques will probably offer the greatest potential for accurate data analysis. The impact of cloud cover or scattered clouds over the ranch of interest can interject real difficulties. This type of dynamic problem, as well as other analysis variables, can be more readily accounted for using an interactive system.

### (7) Temporal Registration

The selected portion of the scene should be registered with previous analyses over the same area. This technique will allow for change

detection analysis and for deriving relationships between different areas of the display.

(8) Spatial Definition of Subscriber Ranches

Individual ranches or ranch strata will be spatially defined in a data base for rapid overlay on the registered images. This technique will allow for efficient extraction of analysis results on a ranch by ranch basis.

(9) Spectral Manipulation for Biomass Analysis

Multispectral data will be ratioed or otherwise normalized to produce a function applicable to range biomass. A description of successful techniques applied in deriving biomass from remotely sensed data is described in Section E.2.

(10) Standing Biomass Estimates

Correlations have been determined relating normalized or ratioed multispectral data from Landsat to green biomass. These correlations were derived from comparisons with detailed ground truth on available forage, weather parameters, and other factors. The ability to accurately assess the biomass from remotely sensed data will require a ranch by ranch or at least a local area applications research program to establish pertinent correlations. Initially derived correlations will need continuous updating until a data base of biomass relationships is firmly established. The result of the biomass calculations would be in terms of (1) available forage/unit area at the decision period; (2) prediction of available forage over monthly decision periods. The probable error in biomass calculations would have to be estimated and properly accounted for in any output products delivered to the rancher.

#### (11) Resource Management Operational Model

The objective of the resource management model is to provide each individual rancher with the decision suggestions he requires, such as cattle stocking rate, at each monthly decision period. Model inputs include standing biomass, time intervals and large, rancher tolerances, current and past stocking rates, current and future stock and feed prices, range behavior, and other parameters. The outputs would be a series of decision suggestions and criteria geared to the individual rancher needs.

#### (12) - (14) Probable Outputs to Ranch Manager

The rancher will depend on the subscription service to provide him with decision suggestions or at least pertinent inputs for his decision scheme. Subscription service outputs would generally be available on a monthly basis, but the subscription organization could sell its services for other applicable decision periods. The type of outputs which will be available to the ranch manager would probably include the following items:

##### a. Available Forage at the Decision Period

A ranch manager may only be interested in an accurate assessment of available forage at the decision period.

Applying his experience and this data, the manager could effect his own decisions.

##### b. Monthly Forage Prediction

A model incorporating range growth and consumption trends could provide the rancher with monthly range condition predictions for up to six months. Such information would be dependent on a thorough understanding of the normal conditions on the ranch.

In general, the longer the subscription service surveys a ranch, the more accurate their predictions should become. A data base of trends and conditions developed over a period of years should provide reliable forage prediction capability.

c. Operations Decision Suggestions

The outputs of the Resource Management Operations Model will include suggestions of how to manipulate all necessary parameters in order to realize maximum profits. Suggestions would primarily affect decisions such as number of livestock to put on a range, when to rotate them, when and how many to remove, and when to provide supplemental feeding. The operations model outputs would include predictions for the entire growing season with updates at each monthly interval.

(15) Management Decisions

The manager would receive subscription service products (tables, maps, personal consultation) and utilize these inputs to effect a management decision. The service must offer a reliable source of pertinent accurate ranch management information which will result in increased rancher profit. The success of the entire remote sensing analysis plan depends on the ranch manager becoming convinced that remote sensing techniques can provide advantageous information worth buying.

## E.7 RANCH SIZES BY ECONOMIC CLASS

The classification "livestock ranch" is defined in the Census of Agriculture 1969 as operations primarily engaged in production of livestock by grazing. The classification, "livestock ranch" was used in 17 western states, Florida, Louisiana, Hawaii, and Alaska. The classification was not used in 29 states in which livestock production is generally considered as consisting of feeding crops or purchased feed to livestock. The economic class categories used in this USDA report were based on sales of farm products. Class 1 had product sales  $> \$40,000$ , class 2 ( $40,000-20,000$ ), class 3 ( $20,000-10,000$ ), class 4 ( $10,000 - 5,000$ ), and class 5 ( $5,000 - 2,500$ ).

LIVESTOCK RANCHES - CHARACTERISTICS BY ECONOMIC CLASS: 1969

Category	All Livestock Ranches	Class 1	Class 2	Class 3	Class 4	Class 5
1. Percentage Distributions						
Number of Ranches	100.0%	13.5%	13.1%	18.1%	24.9%	30.5%
Land in Ranches	100.0	59.0	16.7	11.7	7.2	5.4
Total \$Value of Products	100.0	72.8	11.0	7.7	5.3	3.2
2. Land Averages per Ranch						
(Acres)	3,707 a	16,227 a	4,737 a	2,390 a	1,081 a	657 a.
Total Grazing Land(Acres)	3,555	15,670	4,522	2,275	1,015	616
Cattle & Calves	232	1,009	270	151	86	55
Sheep & Lambs	796	2,618	768	403	206	123



Values for Selected States

PASTURE & RANGELAND FOR SELECTED STATES

(OTHER THAN CROP LAND AND WOODLAND PASTURE)

WITH SALES OVER \$2,500

STATE	NO. OF FARMS	NO. OF ACRES	ACRES/FARM
KANSAS	40,453	14,522,195	358
MONTANA	14,431	39,398,253	2730
NORTH DAKOTA	22,073	9,294,883	421
NEBRASKA	33,294	21,114,717	634
SOUTH DAKOTA	22,462	18,624,803	829
TEXAS	62,512	86,590,162	1385
WYOMING	5,184	27,313,371	5269

**APPENDIX F**  
**INLAND WATER MANAGEMENT**

## PREFACE

The Appendix summarizes the TOSS effort with respect to the Inland Water Management Mission and is the joint product of Melissa Roberts (General Electric) and Martin Putnam (ECON Inc.). During the TOSS effort it was decided to concentrate on the two agricultural missions and to conclude the effort on this water management mission as soon as possible. Thus the material in this Appendix may be of uneven depth-some reservoirs are only summarily treated while others may even include preliminary benefits estimates.

Because of the large size of this Appendix, a table of contents is provided.

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F.7 REFERENCES

## F.1 INTRODUCTION

In the past 5 years a number of studies have been published on the possible impact of satellite-based remote sensing on reservoir management in the Western U.S.\* Most of these consist of case studies or simulations of the operation of a single reservoir, with extrapolations to the rest of the U.S. on the basis of such parameters as installed hydroelectric capacity or irrigated acreage. Apart from the particular merits of these studies as estimates of the benefits to be derived from the dams whose operations they examined, their common methodological approach, extrapolation from a single case, suffers from the very considerable shortcoming that dams in the Western U.S. vary enormously in such essential respects as variability of runoff, fraction of inflows resulting from snowmelt, and ratio of storage to mean annual runoff, to an extent which can affect estimates by several orders of magnitude. Furthermore, there is both substitution and complementarity among different benefits areas, so that an extrapolation of benefits from several reservoirs which have been examined independently may result in significant distortions.

For example, since the seasonal drawdown pattern for optimal hydropower generation is considerably different from that for irrigation, there is a tradeoff between the two benefits areas in the case of reservoirs which are used for both functions and which do not have inflows adequate for simultaneous maximization of both. Therefore an extrapolation of irrigation benefits from a dam used primarily for irrigation, and of hydropower benefits from a dam designed mainly for hydroelectric generation, may systematically overstate expected regional or nationwide benefits.

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\*See, for example, ECO, DMU, WOA and ERS. ECO, DMU, and ERS focus on the economic aspect of the problem; the papers included in WOA are more concerned with technical issues. (For an explanation of abbreviations used in footnotes, see References, Section F.7)



Another factor which introduces systematic bias into extrapolations from the available case studies is that these studies have generally focussed on major Western reservoirs with largely unregulated inflows (e.g. Oroville, Palisades-Jackson Lake, Hungry Horse). Since most large reservoirs are downstream from smaller impoundments, dams such as Oroville and Hungry Horse are the exception rather than the rule. The absence of upstream regulation makes accurate and timely forecasts of inflows much more critical to the management of these reservoirs than it is to most.\* Upstream impoundments generally have the effect of "leveling off" the variability of streamflow for downstream reservoirs. Upstream flood-control space is filled first during periods of heavy flow, while dry-season releases from upstream impoundments serve to maintain steady flows downstream. When there is adequate storage upstream, the effects of misforecasts can be largely absorbed by smaller reservoirs with relatively small sacrifices to the total system's irrigation or hydroelectric output. A linear extrapolation of the benefits of improved information from a single-reservoir system such as Hungry Horse to a large basin such as the Colorado or Missouri system will therefore have a large positive bias. A more appropriate basis for regional and national benefits estimates is a comparative study of dams of different sizes and functions at various relative positions in their respective drainage systems. Because of large regional differences in climate and topography, it is also necessary that the sample be geographically diverse.

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\*In the case of Hoover Dam, which is downstream from many millions of acre-ft. of storage space, the managers estimate that only about 1/2 man-day per month is devoted to activities related to snowmelt and inflow forecasting. This estimate does not include outlays by the Soil Conservation Service, which prepares snowcover reports and forecasts used by the managers of Hoover and many other dams. The SCS's 1974 budget for snow surveys in Utah, Colorado and Arizona was \$236,581. Sources: Letter from John P. Fish, SCS, Washington, D.C. and telephone conversation with Gordon Freeney and Carl Mayer, Bureau of Reclamation, Boulder County, Nev., July 18, 1975.

Nine impoundments have been selected for closer examination with this object in view. An attempt has been made to select as heterogeneous and representative a sample as possible, subject to the constraint that each reservoir in the group be a candidate for remote-sensing applicability. Grounds for selection of individual reservoirs, and constraints on the sample as a whole, are outlined in this appendix as well as more detailed data on each of the impoundments examined.

## F.2 CASE STUDY SELECTION

The discussion which follows presents the rationale which went into the selection of the nine specific Western reservoirs (impoundments) used in this TOSS effort. The overall objective was to select a set of reservoirs which was broad enough and varied enough to be representative of an Inland Water Management mission.

### F.2.1 SELECTION OF REGIONS

The climate and topography of a region sets certain limitations on the potential applicability of satellite-derived snow data for reservoir management. Only those reservoirs which are located in basins with sizeable snowfall could have significant benefits from such information. This criterion automatically rules out the Southeastern United States, where mean annual snowfall is negligible.

Remaining areas, including the Northeastern United States and the West, rely on snow data to varying degrees. In the Northeast the need for snow data is relatively moderate. This stems in part from the topography of the region, which is characterized by fairly low elevations. In these low-lying areas, snow does not accumulate in enormous quantities and is not generally as long

lasting as it is in higher elevations. Therefore snowpack areas do not play a main part in reservoir management and in turn the need for large quantities of snow data is limited.

The other reason for the moderate need for snow data at individual locations in the East is based on the size of the dams and the scope of their activities. Typically, the network of Eastern dams consists of numerous small structures, with lower capacities than the dams in the West. For instance, with limited exceptions, hydropower generating capacities of Eastern dams are one order of magnitude lower than their Western counterparts. Furthermore, this lower capacity and small size is accompanied by a limited range of activities being performed by an individual dam. Most dams are managed for a single, specific purpose (e.g. flood control a/o hydropower generation, but, not irrigation- since irrigation is accomplished by adequate spring precipitation).

In contrast, in the Western region, excluding the low-lying Great Basin area, it is the case that much of the "usable water supply ... originates as mountain snow-fall"\*. Snowpacks in the higher mountain chains may average 200 inches\*\*. Western dams, to accompany this water supply source, are built as large, multipurpose structures. The managers of a single dam may simultaneously regulate flood control, hydroelectric, irrigation, recreation, . . . activities. For example, Shasta Dam, located east of the Cascade Range in Northern California, manages flood control, irrigation, power production, river regulation, and navigation. Detroit Reservoir, draining the same mountain range in Northern Oregon includes the preceding activities and, in addition, water supply control as its functions.

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\*(Supply Outlook for Western United States - SCS).

(\*\*Columbia-North Pacific Study, "Water Resources", Page 349)

The complex interaction between decisions made on various activities at a single Western reservoir places the reservoir managers in the position of needing abundant data. This need extends to snow data. Thus their extensive snowpacks in upper elevations, their large multipurpose reservoirs, and the resulting need for constant awareness of the state of the snowpack make Western dams likely candidates for a benefits evaluation of remotely sensed data and its impact on reservoir management.

#### F.2.2 SELECTION OF RESERVOIRS

Within the Western U.S. region specific reservoirs were selected.

##### F.2.2.1 Selection Criteria

Other things being equals, the greatest benefits from improved data on snowmelt can be expected to occur to large, multipurpose reservoirs in areas where snowmelt constitutes a large fraction of total runoff. Thus, reservoirs which did not satisfy all or most of the following criteria were excluded:

- Location in a Western U.S. basin with moderate to heavy snowfall and elevations high enough to permit the accumulation of a large snowpack.
- Hydroelectric capacity of 100 megawatts or more and/or average annual generation of 1,000,000 megawatt-hours.
- Significant diversions for irrigation or non-agricultural water supply.
- Water storage capacity  $10^9$  cubic meters (810,700 acre-feet).
- Flood-control capability.
- Ratio of reservoir storage to inflow .05.

- Low frequency of cloud cover over the reservoir drainage area during snowmelt season.

#### F.2.2.2 Sample Constraints

The uses and value of snowpack information vary from one reservoir to another depending on factors such as primary reservoir function, location of the reservoir in its drainage system, and the topography, climatology, and size of the basin in which it is located. The following conditions were therefore imposed to ensure a sufficiently diverse sample

- At least one reservoir must be selected from each of the five major Western drainage regions (Missouri, Upper and Lower Colorado, Columbia-North Pacific, and California-South Pacific).
- At Least two reservoirs of each of the following types must be included:
  - 1) An upstream reservoir in a large drainage basin (e.g., Polisades, Blue Mesa).
  - 2) Downstream reservoir in a large drainage basin (e.g., Hoover, Grand Coulee).
  - 3) Large reservoir in a relatively small basin with minor upstream impoundments (e.g., Dworshak, Swift).
- Reservoirs having a variety of different managing agencies with different objectives must be selected (the final list includes dams managed by the Army Corps of Engineers, the Bureau of Reclamation, the Pacific Power and Light Co., and the Turlock and Modesto (Calif.) Irrigation Districts).

#### F.2.2.3 Rationale for Inclusion of Particular Reservoirs

#### F.2.2.3.1 Colorado Basin

##### F.2.2.3.1.1 Hoover

Hoover may be regarded as the paradigmatic multipurpose downstream reservoir, with over 4 million megawatt-hours mean annual generation, and significant flood control, irrigation, and water supply functions. Most of Hoover's inflow is derived from snowmelt in the mountains of Colorado and Utah, but this flow reaches Hoover only after extensive regulation. An examination of Hoover's information requirements may therefore be expected to have implications for other multipurpose reservoirs with extensive upstream impoundments.

Installed hydroelectric capacity:	1,340 MW
Average annual generation:	4,111,000 MWH
Storage capacity:	29,827,000 acre-ft. (approx.)
Drainage area:	167,800 sq. mi.
Purposes:	hydroelectric, irrigation, flood control, navigation, water supply
Ownership:	Bureau of Reclamation

##### F.2.2.3.1.2 Blue Mesa

Blue Mesa is a medium-sized multipurpose reservoir about 75 miles downstream from the headwaters of the Gunnison River, which flows into the Colorado. Relatively heavy annual snowfall (100-400 in/yr) and high basin elevations make snowmelt forecasts an important element in reservoir management. Because inflows are highly seasonal and relatively unregulated by upstream impoundments, flood control is one of Blue Mesa's primary functions (mean inflow in June is 12 times mean flow in February). Forecasting and management problems at Blue Mesa may be expected to be representative of upstream reservoirs with highly variable inflows derived largely from snowmelt.

Installed hydroelectric capacity:	60 MW
Average annual generation:	280,000 MWH
Storage capacity:	941,200 acre-ft.
Drainage area:	3543 sq. mi.
Purpose:	irrigation, hydroelectric, flood control
Ownership:	Bureau of Reclamation

#### F.2.2.3.2 California Basins

Shasta is the keystone of California's Central Valley Project, an extensive network of impoundments of various sizes which provides irrigation, hydro-power, flood control and other services to residents in the Sacramento and San Joaquin Valleys. Shasta itself occupies an upstream position in this system, with only a small fraction of annual inflows subject to significant prior regulation. The absence of prior regulations contributes to the high variability of Shasta's inflows; at the same time, Shasta's key position in its irrigation and hydroelectric network multiplies the consequences of major errors in forecasting or management. Shasta's inflows are derived from a mixture of rainfall and snowmelt, with rainfall the more significant of the two.

Installed hydroelectric:	420 MW
Average annual generation:	1,727,800 MWH
Drainage area:	6,665 sq. mi.
Purposes:	Irrigation, hydroelectric, flood control, navigation
Ownership:	Bureau of Reclamation

#### F.2.2.3.2.2 New Don Pedro

This reservoir was selected as representative of the central California impoundments which are used primarily for irrigation. With headwaters in

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the Sierras near Yosemite, Don Pedro receives most of its inflow from snow-melt, but upstream regulation reduces flow variability somewhat. Unlike Shasta, Hoover, and Blue Mesa, Don Pedro is in a middle position in its drainage basin, and in this respect is typical of most Western reservoirs. In addition to irrigation, Don Pedro also has a significant hydroelectric capability.

Installed hydroelectric capacity:	136.5 MW
Average annual generation:	598,400 MWH
Storage capacity:	2,030,000 acre-ft.
Drainage area:	1530 sq. mi.
Purposes:	Irrigation and Hydroelectric
Ownership:	Turlock and Modesto Irrigation Districts

#### F.2.2.3.3 Missouri Basin: Yellowtail

An examination of Yellowtail's forecasting requirements should provide grounds for generalization to other upstream Missouri impoundments. Yellowtail, which controls drainage from the Bighorn Basin, is downstream from a number of smaller flood-control dams but upstream from such large Missouri River reservoirs as Fort Peck and Lake Sakakawea. It is large enough to realize significant benefits from more efficient operation but far enough upstream to have considerable variability of flow. Much of Yellowtail's inflows are derived from snowmelt from the Bighorn and Wind River ranges.

Installed hydroelectric capacity:	250 MW
Average annual generation:	910,000 MWH
Storage capacity:	1,375,000 acre-ft.
Drainage area:	19,600 sq. mi.



Purposes: Irrigation, hydroelectric, flood control  
Ownership: Bureau of Reclamation

F.2.2.3.4 Snake River Basin

F.2.2.3.4.1 Palisades

Palisades is a moderately large multipurpose upstream Snake River reservoir with a mix of regulated and unregulated inflows. Most of Palisades' runoff results from snowmelt and both the reservoir and most of its drainage area are located in mountainous terrain. Accurate ground-based snowcover observations could be expected to be correspondingly difficult to obtain.

Installed hydroelectric capacity: 118.8 MW  
Average annual generation: 610,000 MWH  
Storage capacity: 1,400,000 acre-ft.  
Drainage area: 5208 sq. mi.  
Purposes: irrigation, hydroelectric, flood control,  
conservation, municipal water supply  
Ownership: Bureau of Reclamation

F.2.2.3.4.2 Dworshak

Like Oroville, Dworshak is a large, multipurpose reservoir with largely unregulated inflows. Dworshak's basin is at relatively high elevations, and approx. 80% of inflows are derived from snowmelt. Because of its similarity to Oroville and strong prima facie indications of remote-sensing applicability, Dworshak constitutes a significant test for the generalizability of the Oroville results to other regions.

Installed hydroelectric capacity: 1060 MW  
Average annual generation: 1,120,000 MWH

Storage capacity: 3,453,000 acre-ft.

Purposes: flood control, hydroelectric, navigation, recreation

Ownership: Army Corps of Engineers

#### F.2.2.3.5 Columbia Basin

##### F.2.2.3.5.1 Grand Coulee

As the largest dam in the Columbia system (and in the United States), Grand Coulee is of interest more as a significant single source of potential benefits than as a representative case to be generalized. A large fraction of Coulee's runoff is derived from snowmelt in Idaho, British Columbia and Washington; the water is used mainly for hydropower and irrigation.

Installed hydroelectric capacity: 2100 MW

Average annual generation: 16,330,000 MWH

Storage capacity: 9,562,000 acre-ft.

Drainage area: 74,700 sq. mi.

Purposes: Irrigation, hydroelectric, flood control, navigation

Ownership: Bureau of Reclamation

##### F.2.2.3.5.2 Swift #1

Both the climatological and management parameters of Swift are significantly different from those of the other dams in the sample. Located on the Western slopes of the Cascade Range in Washington, Swift's drainage area has large runoff contribution from rainfall as well as snowmelt. Snowmelt is nevertheless a large enough runoff component to require an extensive array of snow courses for runoff forecasting. Inflows are not significantly regulated by upstream impoundments. Since Swift is operated almost exclusively for hydro-

power generation, it may provide a stronger basis for benefits extrapolation to other single-purpose reservoirs than do the other impoundments in the sample.

Installed hydroelectric capacity: 204 MW

Average annual generation: 642,000 MWH

Storage capacity: 755,000 acre-ft.

Drainage area: 481 sq. mi.

Purpose: hydroelectric

Ownership: Pacific Power & Light

### F.3 RATIONALE FOR BENEFITS

#### F.3.1 HYDROELECTRIC BENEFITS

##### F.3.1.1 Spillage Reduction

Since spilled water is practically pure waste from the standpoint of hydroelectric generation, a reduction in spillage represents a clear benefit to reservoir management if it can be achieved without sacrificing economic or technical efficiency. Unnecessary spillage may result from either underforecasts or overforecasts. Spillage results from underforecasts when reservoir managers, in an attempt to keep the reservoir as full as possible, leave insufficient room for future inflows. When greater-than-expected inflows occur, spillage is necessary to keep the reservoir from overfilling. A better projection of future inflows would result in larger discharges through the turbines early in the season and less forced spillage later on (see Fig. F.3.1).

Spillage may also result from overforecasts. At some reservoirs, spillage is required prior to the peak runoff season to draw the storage level down

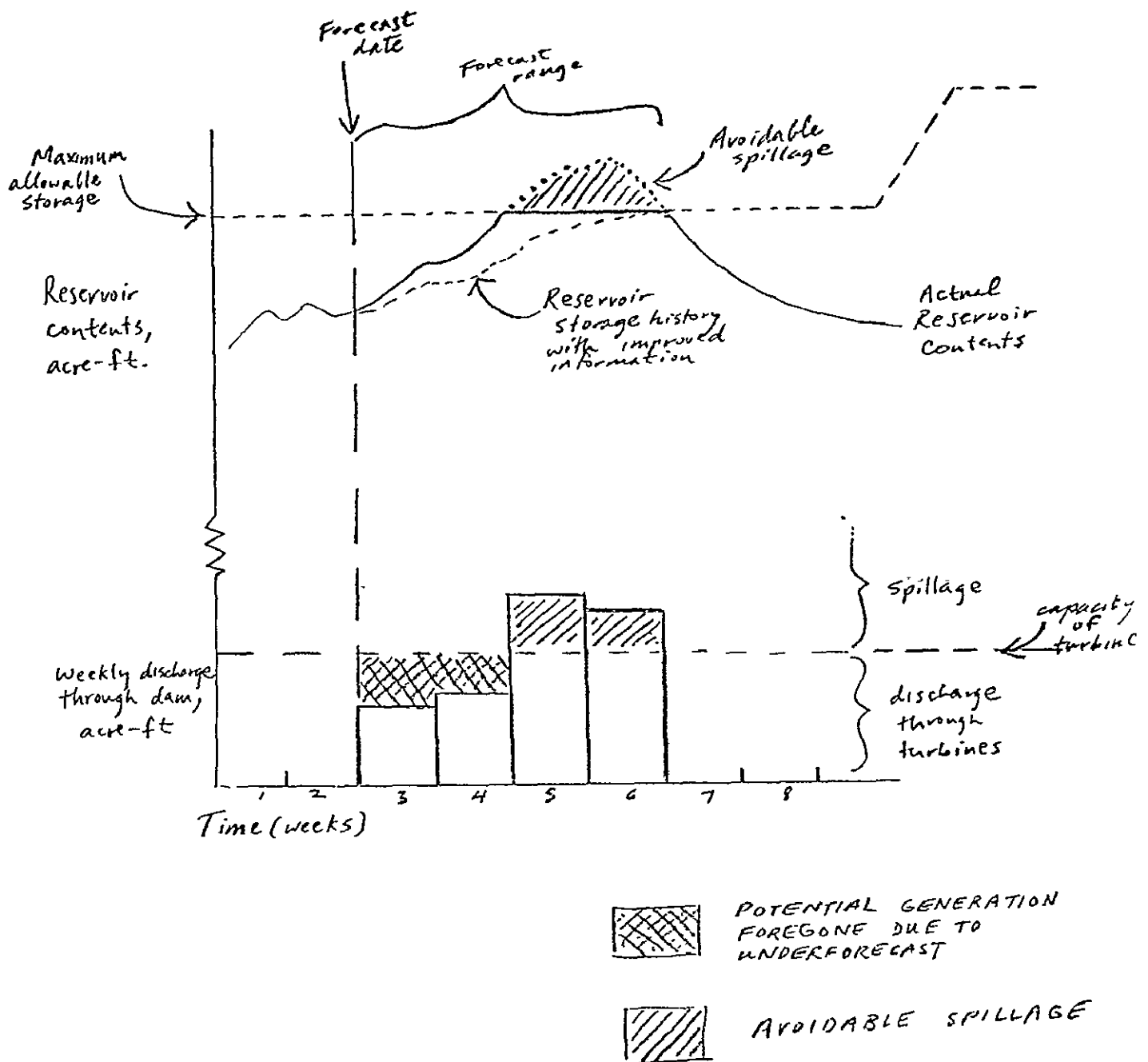


Figure 3-1 Avoidable Spillage Due to Underforecast. With Improved Information, Increased Generation in Weeks 3 & 4 Could be Substituted for Spillage in Weeks 5 & 6.

to accomodate expected inflows. If projected inflows are greatest than actual inflows, this anticipatory spillage may be larger than necessary (see Fig. F.3.2).

#### F.3.1.2 Increases in Technical Efficiency

A hydroelectric plant is a device for converting the gravitational potential energy of a column of water into electrical energy. The higher the column of water, the more potential energy there is to be realized. As a general rule, therefore, more electricity can be generated from an acre-foot of water when the reservoir is full than can be generated when it is only partially full. The relationship between KWH/AF and the depth of water in the reservoir can be plotted on the basis of historical data, the result is a scatter diagram with can be approximated by a linear regression equation (see, for example, Fig. F.6-2).

The "scatter" in the relationship is explained by the fact that the output of electric power per unit discharge depends on a number of factors other than gross reservoir level. The level of water in the pool below the dam partially determines the effective height of the column of water which drives the generators. In addition, most turbines are designed to produce peak output at some optimal discharge rate; when the load on the generating station dictates less-than-optimal discharges, the efficiency of the system declines.

Despite these factors, there is a clear long-run relationship between gross head and the rate of hydroelectric output. In the estimates which follow, it is assumed that least-squares linear regressions of historical data provide reasonable approximations of this relationship.\* In the text which follows,

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\*In the case of Blue Mesa and Hoover Dams, estimates have been based on equations supplied by the Bureau of Reclamation. The estimation method used for Shasta is summarized in Section F.6.2.3.2.

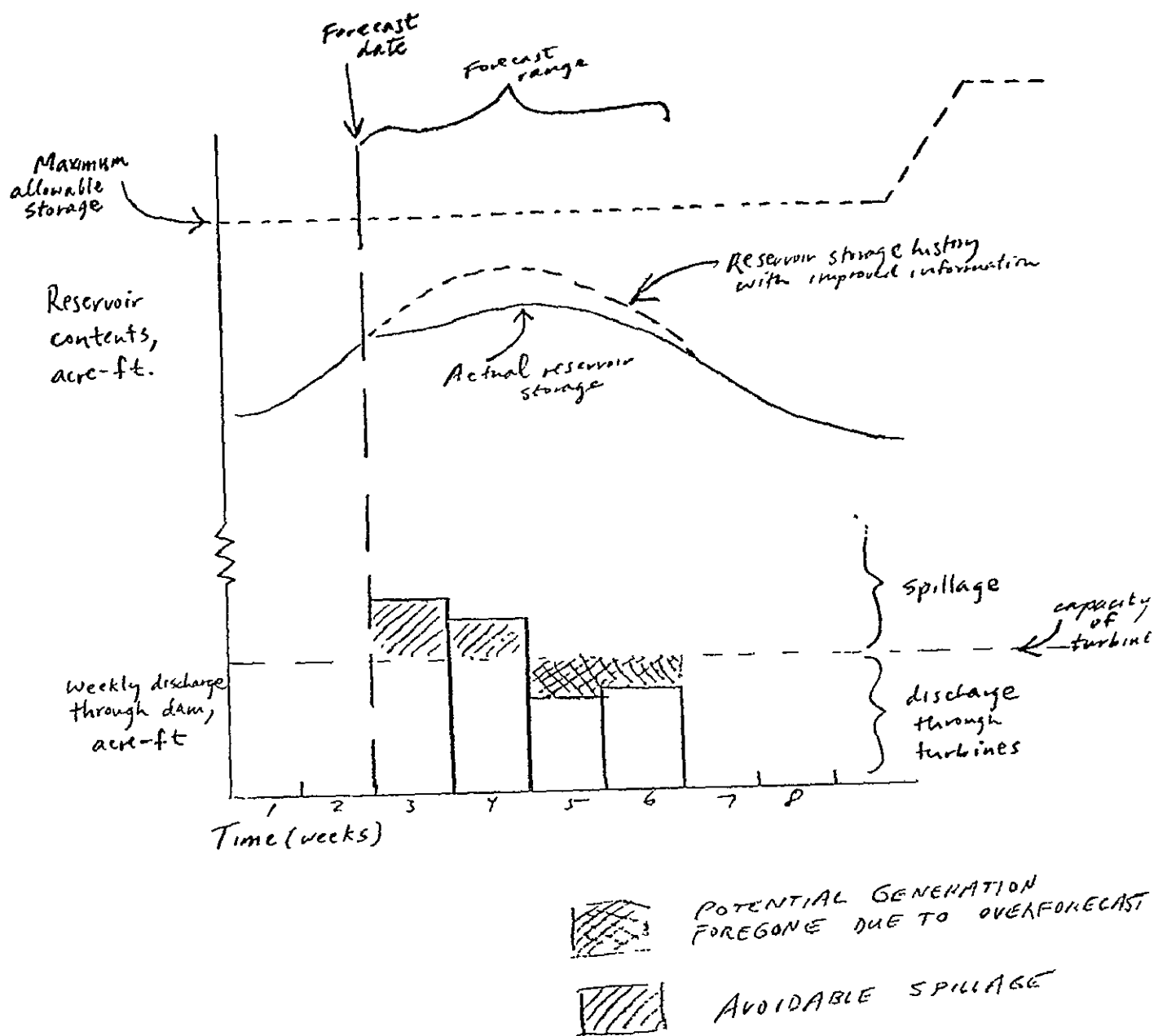


Figure 3-2 Avoidable Spillage Resulting from Overcast. With Improved Information, Increased Generation in Weeks 5 & 6 Could be Substituted for Spillage in Weeks 3 & 4.

the term "technical efficiency" is used to refer to the output of hydro-electric power per unit discharge (KWH/AF). Since other uses of the term "efficiency" are common, it should be emphasized that in this text the phrase "technical efficiency" is used in the sense indicated here.

Losses in technical efficiency are caused most often by overforecasts, which result in excessive drawdowns and less-than-optimal reservoir storage levels. Underforecasts rarely result in losses in technical efficiency, since the typical management response to a low forecast is to restrict outflows in order to raise storage levels.

#### F.3.1.3 Improvement in Economic Efficiency

A benefits pattern similar to spillage reduction is available at some dams where the generating capacity is sufficient to avoid almost all spills. At such installations, drawdowns are generally taken through the generators rather than the spillways, since the net value of hydropower generation, even during low-demand periods, is at least greater than zero. For a generating station designed mainly to handle peak loads, however, a misforecast may result in excessive off-peak generation at one time and inadequate storage for peak generation at another time. Since the price ratio of peak to non-peak power is on the order of 3 to 1, such distortions in the generation pattern may have disbenefits approaching those associated with unnecessary spillage.

#### F.3.2 FLOOD-CONTROL BENEFITS

Though most dams are managed to reduce the probability of damaging downstream flooding to a very low level (e.g., .01 or less), an occasional forecast exceedence may be large enough to mandate spillage which results in actual

flooding. The potential benefits associated with reducing the probability of such a misforecast are very likely quite large, but are also likely to resist reliable quantification, since the relevant data base for evaluating events of such low frequency is often quite narrow.

#### F.3.3 IRRIGATION BENEFITS

Irrigation benefits from improved runoff information could result either from increases in irrigated acreage, in heavy water years, or from reductions in planting and hence reductions in costs in dry years. Increases in long-term mean forecast reliability could also increase mean cultivated acreage by reducing long-term average costs. However, the realization of such benefits generally requires a forecast range considerably longer than that available from satellite data. Planting decisions in most areas under irrigation are generally made in advance of April 1, when the definitive runoff forecasts in most basins appear, and the January and February forecasts, on which many agricultural decisions must rely, have a large error component arising from both late-winter snowfall and spring precipitation. Thus, though further research on crop calendars is required to substantiate this point, considerations of timeliness almost certainly would seriously limit the benefits to agriculture to be expected from improved measures of snowpack for runoff forecasting.

#### F.3.4 COST SAVINGS OVER ALTERNATIVE SNOW SURVEY METHODS

Despite the low marginal cost of satellite-based measures of snowpack areal extent, the expected cost savings to be derived from the implementation of such a system are not large. This is true for two reasons. First, current outlays for ground-based snow surveys are relatively small. In 1974, for example, the Soil Conservation Service spent a total of \$1,115,727 on all



its snow-survey activities. Costs of survey activities by other State and Federal agencies, though not included in this figure, are of this order of magnitude. Second, the fraction of current survey costs that could be saved by Satellite-based areal extent information is a small percentage of total outlays. Most current survey expenditures are either for information which supplements but could not be replaced by areal extent information (e.g. measures of snow water equivalent), or for activities which would be required by any data-collection and forecasting system (e.g., processing of data, construction and operation of forecasting models, dissemination of results).

#### F.4 INTERACTION BETWEEN RESERVOIR-MANAGEMENT PARAMETERS AND BENEFITS MECHANISMS

The properties of individual dams and reservoirs set limits on the expected benefits to be derived from remote sensing via the benefits mechanisms outlined above. These include:

##### F.4.1 SPILLAGE HISTORY

Though all spillage is waste with respect to the installation where it occurs, not all spills could be avoided even with perfect information.

The following spills are not avoidable by improved April 1 forecast information:

- (a) Spills which occur because annual flow through dam exceeds annual discharge capacity of the dam's turbines.
- (b) Spills resulting from short-term inflows greater than the sum of reservoir storage capacity and the integral of turbine discharge capacity over the period of such inflows; spills of this type are common at run-of-river installations, where the dam's storage capacity is a small fraction of monthly flow.

- (c) Spills which result from early-season (pre-forecast) draw-down for flood-control purposes. These spills can be reduced only if there is an improvement in long-range forecasts sufficient to justify reduced flood-control margins. Satellite-derived information on areal extent of snowcover does not appear to be appropriate for the improvement of long-range forecasts; such information therefore cannot be expected to affect early-season spillage.
- (d) Spillage resulting from downstream requirements for irrigation or hydropower.

Spillage not falling in one of the above categories may be reduced by improved April 1 forecast information, but only in an amount corresponding to the magnitude of forecast improvement. For example, if mean April-July runoff is 1,000,000 acre-feet and mean April 1 forecast error is reduced from 10% to 7 1/2%, potential spillage reduction is approximately 25,000 acre-feet.\*

#### F.4.2 REDUCTION OF DISCRETIONARY NONPEAK GENERATION

Though nonpeak generation sometimes amounts to avoidable "spillage through the turbines" ("power-dumping") and results in sacrifices of peak power at some other point in the season, many hydroelectric plants are designed to produce a large fraction of total output at nonpeak hours.

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\*If spillage decisions are determined by peak rather than historical mean forecast error, this figure may be misleading. For example, if forecast improvements reduce mean error to 7 1/2% but expected peak error remains at 20%, there may be no spillage-reduction benefits from improved forecast information. However, the calculation above provides an order-of-magnitude approximation of the possible benefits from this source.

The economic cost of off-peak generation, if any, is a function not only of the peak/off-peak generation ratio but also of such factors as foregone peak generation, storage capacity as a fraction of annual flow, the relationship between generation capacity and annual flow, and the relationship between a generating station and the system which it serves. Because the quantification of several of these factors is beyond the scope of the present study, only qualitative evaluations are provided in the case study reports which follow.

#### F.4.3 INCREASES IN TECHNICAL EFFICIENCY

The relationship between hydroelectric generation and reservoir storage level is summarized in section F.3.1.2, above. The quantification of benefits from this source in particular cases involves.

- (a) derivation (from historical data) of a regression line relating gross head with KWH per acre-foot
- (b) estimation of the possible reduction in mean forecast error by improved snowcover information
- (c) examination of the historical pattern of filling and discharge of the reservoir to determine whether forecast errors can be compensated in the course of the runoff season to restore reservoir storage to an optimum level
- (d) evaluation of the effect of upstream regulation, if any, on the reservoir's storage and discharge patterns.

The result of this examination of a reservoir's forecast and management parameters is a hypothetical alternative storage-level map, that is, an estimate of the changes in gross reservoir storage levels which might result from improvements in forecast information. Integration of this estimate with

historical data on runoff and on the relationship between technical efficiency and storage level yields an estimate of the aggregate potential increase in hydropower generation at the site.

#### F.4.4 RELATIONSHIP BETWEEN FORECAST RANGE AND LOCAL CROP CALENDARS

It follows from the remarks in Section F.3.3 that significant remote-sensing benefits resulting from timely adjustment in irrigated acreage planted could arise only for crops planted after most of the snowpack has accumulated.

However, other categories of irrigation benefits may result from decisions made in mid-season, e.g., a decision in an unusually dry year to concentrate the available water supply on a fraction of total acreage planted. A complete evaluation of irrigation benefits thus requires data, for each sub-basin, on planting schedules and on water requirements at later points in the crop cycle.

#### F.5 SNOPACK DATA COLLECTION AND DISSEMINATION TO RESERVOIR MANAGERS

Efficient operation of a reservoir depends upon the accuracy of streamflow forecasts. Streamflow forecasts are needed to: (1) determine permissible releases for power, irrigation, or municipal uses with assured refill; and (2) meet mandatory release and storage requirements for recreation, pollution abatement, and flood control. Where, as in the West, much of the streamflow results from snowmelt, forecasting procedures depend heavily upon snowpack measurements.

The Soil Conservation Service (SCS) is the major coordinator of snow data collection in the West. SCS disseminates snow data to water resource managers via a monthly publication entitled Water Supply Outlook.

#### F.5.1 TYPES OF DATA COLLECTED FOR STREAMFLOW FORECASTS

The most extensively gathered types of snow data are depth and water equivalent. These are collected through the use of a sampling tube which penetrates the full depth of the snow. On the outside of the tube is an inch scale which indicates the depth of the snow. Water equivalent is determined by bringing the tube to the surface and weighing it. The places where snow data are collected are called "snow courses". These are about a thousand feet long, and sampling points are located 50 to 100 feet apart. In cases where a snow course is too hazardous or costly to reach, snow surveyors record the snow depth by observing graduated snow markers from an airplane. As the airplane passes over the snow course, the surveyors count the number of crossbars showing above the snow, and estimate the distance to the snow surface from the lowest crossbar that shows. Through this method, snow depths can be measured to within 3 inches.

Snow samples are taken once a month, from the beginning of January to the first of June, at 5 to 10 spots in each snow course. Readings from the sampling points are averaged, then extrapolated to the rest of the snow-covered area through the use of mathematical models.

#### F.5.2 EVALUATION OF PRESENT METHODS OF DATA COLLECTION

Although several reservoir managers felt that SCS snow data was adequate, they noted that there were particular features of the data base and data collection methods that were not quite satisfactory. Usually this factor did not cause any major problems; however, in certain situations it did lead to substantial losses in efficiency. In these cases the reservoir managers expressed a great desire for improvement in their data supply.

One such instance was at Dworshak reservoir last year. At Dworshak, a reservoir forecast for runoff was made using several data sources, including SCS cores, aerial reconnaissance without photography, snowline estimates, etc. The forecast differed from actual runoff by a considerable degree (an estimated 25-30%). This discrepancy was in part attributed to an unusual snowfall pattern, and, hence, unreliable data measurements.

Although Dworshak is a fairly new impoundment (built in 1971)--and thus it would be unsafe to judge as to which aspects of the data or how much the data was at fault,--it is certain that inaccurate data did have something to do with the miscalculation; and, furthermore, that this same situation could occur at any reservoir using inaccurate data to forecast runoff.

Data deficiencies which may have contributed to the error at Dworshak and at other reservoirs were discussed by managers of these reservoirs. At Dworshak reservoir and at most, if not all western reservoirs, water-equivalent data, obtained from sample cores, is the major measurement used in forecast models. As mentioned in the previous section, the cores are collected at 5 to 10 spots for selected snow courses. Thus, in essence, microlocations are being sampled to analyze a total area. No matter how carefully the courses are selected, an unusual situation, such as the snowpattern at Dworshak last year or a snowdrift on the sampling area, can result in a gross overestimate or underestimate of total snowfall in a basin. This was the most common and major criticism expressed by managers of the 9 selected reservoirs.

Despite possible misrepresentative sampling connected with snow coring, many managers found that SCS forecasts have been good enough and they are fairly accurate. Nonetheless, most did cite areas, specific to their basins, which were and are open to improvement. For example, one manager pointed out that

over the years a snow course station may be added or dropped at a given basin, rendering comparison or averages made from successive data files inconsistent. This type of historical record may be needed for future runoff calculations.

Another problem with water-equivalent data is tied to "timeliness". Data for one of the reservoirs is mailed to its manager by postcard. Often the data does not arrive until the middle of the month, whereas decisions should be made at an earlier date. The lack of immediate arrival of the data at this reservoir probably hinders the management from making optimal decisions.

In some other-cases it is the frequency of data collection that is blamed for inefficient decisions. Since data cannot be updated during the course of a month, without supplementary data, reservoir managers are unaware of the condition of the snowpack during the interval between collection times. During the season when the snowpack is actively melting (April to July) the availability of more frequent data could be beneficial to some managers.

Lastly, a problem associated with snowcoring is the physical labor, time, and risks involved in gathering data. Presently, SCS surveyors cover 20,000 miles by foot and 30,000 by snow machines to collect cores (SCS). Possibly much of this effort could be saved by other methods of collection and/or other types of data, such as aerial extent data.

#### F.5.3 DATA PARAMETERS RELATED TO RESERVOIR MANAGEMENT

In a limited number of cases, the people associated with agencies involved in snow collection and/or those managing the 9 selected reservoirs specified "optimal data parameters". The estimates that they gave were speculative rather than based on firm data; hence, they should be viewed cautiously and

in the context of the entire study (especially Individual Case Studies). Table F.5-1 summarizes these estimates.

Although each reservoir has data needs which are uniquely related to its location and management, there is slightly more consistency among these (present and desired) data bases than Table F.5-1 may indicate. Thus a summary of the overall data situation is in order.

Typically data collection is done by or under subcontract to the SCS. The SCS then disseminates the data for a particular basin to the reservoir managers in question. Data relayed to reservoir managers include raw figures, which are then used, along with other variables, in a reservoir-determined forecast equation. However, the SCS also sets up its own forecasts for runoff, which are published after each monthly observation. These include any data pertinent to the forecast area--for example, average runoff rate for the basin and weather conditions prior to the forecast. Later, some of this data is stored for historical record in computers.

Since the SCS gathers and updates its data monthly, this is the frequency with which data is received at reservoirs. Unless reservoir operators supplement SCS information with their own, they have little knowledge of the basin snowpack from one month to the next. Many times, reservoir managers could plan their operations more effectively if they had a clearer picture of what changes have occurred in basin conditions after their last forecast was made. For example, a big storm may cause sudden and unexpected runoff. In instances where reservoir levels are changed daily, (as is the case with Blue Mesa), warning of such runoff, as well as an accurate measurement of the snowcover left after depletion will affect short-term management.



User or Person Commenting	Data Type	Frequency	Timeliness	Accuracy and/or Desired Data	Some Areas Surveyed	Snow Location & Duration	Comments
Grand Coulee	Snow-water equiv	Jan 1 - June 1/mnth * - June 1/mnth Optimally after every snow storm Feasibility - 1/wk					See Footnote 1
Don Pedro	Runoff forecasts (snow-water equiv)	~ May 1 * updated 1/mnth more freq		*Data could be more accurate, especially Jan-Feb *Could use "saturation of snow"		L Sierras A Yosemite P Oct, really Nov-March Jan or Feb	
Hoover	Snow-water equiv	1/mnth (end of mnth)		*Could use "soil moisture"	54 stations (including Colorado & Wyoming Wolf Creek Pass Colorado River (main stem) Rio Blanco Unta Mts)	L Rockies (Col) Utah A Oct, or Sept M Late March, really April (may get snow in June & runoff in Aug)	
Yellowtail	Snow-water equiv	April-July	April-July monitoring important				
An Agency (Portland) Ore	Aerial w/o photos		* operational (?)				This data is recent & not widespread
An Agency (Kansas City)	Aerial	Daily for any improvement, in winter 1/wk					Not presently used

User or Person Commenting	Data Type	Frequency	Timeliness	Accuracy and/or Desired Data	Some Areas Surveyed	Snow Location & Duration	Comments
An Agency (Portland)	Aerial	* → 1/ wk would be an improvement		*Can't tell saturation is fresh snow			Experimental data
Dwarshak	Snow-water equiv. Automated snow-meas. sites Flight w/o photos	Monthly  Several times/daily 3 or 4/season		*Aerial extent data could have cut error (~25%-10%)  *Variability great didn't use photos			Based on last yrs. data ('74?)
Blue Mesa	Snow-water equiv	Jan 1-June 1/mnth → (can be May or July too)			Above Lee's Ferry, above Flaming Gorge Res at up to 50 courses	A Oct-April M April-July ~2/3 runoff	See Footnote 1
Palisades (Coulee) also	Aerial extent	→ 1/wk	*Do use aerial extent in Spring a little, little variation in Jan-Apr snow cover, aerial extent Apr. Better forecasts could be used for Power Jan-Apr	*Would like more sample pts than presently collected via snow core		L In winter-mid May entire basin covered A Oct-mid-May	See Footnote 1
Yellowtail	Snow-water equiv.	Jan 1 (Montana) or Feb 1 (Wy) 1/mnth†	†			L Windbasin Shoshone Aberserkey Range not on Bighorn (East) A Oct, really Dec	

Key for Table

- \* This point was mentioned specifically (in terms of needing improvement)
- ♦ Good enough already
- L Main location
- A Accumulation period
- P Peak snowfall
- M Melt season

Footnote 1 - This person mentioned telemetry

Several reservoir managers noted that this situation is being corrected and that daily snow readings may soon be within reach. SCS is implementing telemetry, a means of surveying and transmitting data to reservoirs on a more frequent, possibly continuous basis. However, telemetry still has a few years to go--e.g., an estimated 5 years until it is completely installed in the Snake River Basin and 5 to 10 years for the Columbia System. Until telemetry becomes an operational system, frequency of data remains a problem for some managers.

The same management areas which require timely data also require accurate data since a miscalculation of such data as the snowcover can drastically affect runoff forecasts and thus management decisions throughout the river system. At this point, however, whereas other parameters are easily summarized, it is hard to generalize about the degree of data accuracy required by various reservoirs. It should suffice to say that accuracy is variable from reservoir to reservoir, and, that in most cases it is open to improvement.

#### F.5.4 REMOTE SENSING OF SNOWPACK AS IT STANDS NOW

Studies have found satellite (LANDSAT) images to be useful for distinguishing snow cover deeper than 2.5 centimeters from surrounding terrain (HTS). The snow-land contrast occurs due to comparatively high reflectivity of snow and it is notably clearest in the MSS Band 5 (.6 to .7  $\mu\text{m}$ )--or short wavelength-range. Using this wavelength, researchers have compared LANDSAT to aerial surveys. Their calculated percentage difference between LANDSAT imagery and high altitude photography, for mapping snowline and aerial extent, is in the range of  $\pm 5\%$  or  $6\%$  (LRG). Additionally, although aerial photography exhibits better resolution than LANDSAT imagery, the information derived from each for purposes of snow mapping is similar.

Thus far, several difficulties have precluded satellite photography as an operational method for snowmapping at reservoirs --e.g., cloud cover, forest cover, shadows, and highly reflective rocks. Among these, the instance of cloud cover is most prevalent. For example, most reservoirs drain mountainous areas where major snowpacks accumulate. When these high altitude areas are located near the ocean, the maritime air masses are lifted over the mountains, condensing into rain or forming heavy cloud cover in the reservoir drainage area (this is called "the orographic effect"). This cloudcover obscures the snowpack and thus makes areal extent estimates of snow unobtainable.

However, techniques are being developed to deal with such difficulties. For instance a set of criteria has been compiled to aid in clarification of the interpretation of snowpack in a cloud covered area. When this and other techniques become usable on a daily basis to laymen, the advantages of LANDSAT (MSS 5) over aerial photography may become more meaningful.

The questions still remain, even with its advantages would satellite photography be a feasible mechanism for predicting snow runoff? Would it yield usable variables? In connection with variables presently used in snow forecasts (snow-water equivalent, depth, snowline, and less frequently, areal extent), only areal extent and snowline are mappable from LANDSAT. Snowline has been particularly useful for forecasts since studies have shown that a decrease in horizontal extent of snow can be correlated with the increase in streamflow (POS, p. 321), and that this decrease in the extent of snowcover can be extrapolated from a small area to a large one.

To a small degree, depth has also been mapped from satellite images. Its mappability however is a function of the variability of the brightness of a photo; and, relevant brightness variation is only detectable with snow depths of 15 cm (6") to 25 cm (HTS). Since major snowpacks consist of snow which approximates 20 feet, the depth-brightness correlations are only beneficial in terms of locating "frost", which is not a major contributor to runoff.

Once operational, the improvement of snow forecasting variables could affect many areas of reservoir management. Some studies have been done evaluating the general (potential) contributions of "ERTS parameters" to the areas under assessment in this study - hydropower generation and irrigation. These have been based on simplified models of the interrelationship between snow-water supply and the aforementioned resource areas at reservoirs. For example, a typical hydropower generating plant, e.g., Blue Mesa or Grand Coulee, may follow a set pattern. In the winter, the demand for their power is at a peak. Since snow is accumulating, there is no inflow from snowmelt into the reservoir. The reservoir must be drawn down to supply water for power. Also, supplementary costly fuels such as oil may have to be added to the (demanded) power supply. Later, in springtime, when demands for power generation decrease, the runoff period starts, water inflow may equal or be greater than the demand for water; in such a situation if the extent of winter snow and therefore amount of water flowing to the reservoir is unknown much "excess" reservoir water will be released in spring in order to provide buffer space for flood control. Then in winter when water is demanded, there will be no supply. If the amount of expected water is known and planned for, it can be stored and used at a more important time, i.e., winter.

Irrigation, the other area under study, is greatly constrained by water supply information. When farmers plant their crops (seed) they may over seed-using more seed and fertilizer than can be handled by future water supply. Thus whereas a few healthy wet crops (dry crops) could have been brought to maturity with an adequate water supply, (if it had been expected) if over-planting takes place either many crops will receive an inadequate water supply or some crops will be raised at the expense of others. Good water supply data can prevent this situation. One study compared those who studied forecasts to those who didn't on approximately 13 mill acres (not owned by the public-Bureau of Reclamation). Vast monetary savings resulted in those cases where forecasts were followed (SSD, p. 84).

#### F.5.5 SELECTED RESERVOIR MANAGERS' VIEWS ON LANSAT AND FUTURE SATELLITE SNOW MONITORING

Reservoir managers present a wide spectrum of attitudes towards remote sensing of snowpack, ranging from enthusiastic to critical. A few managers display very limited interest in satellite monitoring for the reason that there is little need for new information at their reservoirs. Others appear anxious to receive any data possible and look forward to remote sensing.

Managers of large "downstream" reservoirs classify themselves as having little potential for satellite monitoring since runoff reaching the reservoir is small in relation to reservoir capacity. This situation occurs, to some extent, at two or three reservoirs studied. At Hoover, storage is two times as much as inflow. Any unexpected runoff can be contained. Don Pedro also has enough buffer space, with an estimated annual runoff of two million acre-feet -- the same as its capacity. Deviations in runoff do not drastically affect their decisions and thus improved information is not deemed "essential".

Although its situation is mildly different from the one above, Yellowtail falls into the same category -- new data is not essential. Runoff reaches Yellowtail late in the season, after regulation by several upstream impoundments. Thus, Yellowtail has adequate time to plan for events and make management decisions. In general, the managers of Yellowtail seem satisfied with their present information inflow (including timeliness and frequency) and hesitate to suggest that new information would yield benefits to their operations.

Managers of large downstream reservoirs mention that the need for data, including areal extent data, probably exists at dams in positions different than their own, i.e., "upstream" dams and new dams. This seems to be the case. At Dworshak, a fairly new impoundment, the estimated runoff from snowmelt is 80 to 90 percent, but, an advance forecast from snowmelt calculation has been difficult to obtain. This is attributed partially to the absence of areal extent data. Palisades Reservoir, located upstream on the Snake River, receives its data in the usual manner -- snow coring, a limited number of sampling points, and a little aerial extent data in the springtime. Although no specific complaints are made about present data and associated errors, a desire exists for more aerial extent data that could be integrated into the Palisades forecast equation.

All in all, experience with satellite photographs has been extremely limited for most reservoir managers; thus, their comments were very abstract. Those involved in snow collection and forecasting such as the SCS, the River Forecast Center, or the Corps of Engineers had slightly more to say on the matter. A synopsis of their comments would include the following. There is



a need for more accurate snow measurements", but, LANDSAT is lacking in several respects. Among these, its coverage is too infrequent to yield tremendous advantages and much skill is needed to interpret the photographs satisfactorily. For example, last year, if LANDSAT results had been implemented at Fort Peck around July 27, there would have been a 15 percent overestimate of snow coverage (27% as opposed to 12% by aerial flight) and hence a large error of runoff predictions obviously, this has led to some dissatisfaction with the present LANDSAT system. However, one individual from the SCS felt that improved aerial extent data in conjunction with other data would aid forecasting, at least in small basins. And, one manager felt that whereas benefits from improved forecasting at a single reservoir, such as Grand Coulee, may not be appreciable, better upstream forecasts would provide important real benefits to the system as a whole.

The success of satellite remote sensing in supplying the data that would truly improve reservoir forecasts has not yet been established. Subsequently very few people are willing to state specific tangible areas that will benefit from satellite data. On the other hand, the majority of water resource managers appeared to be fairly optimistic and interested in what this system may have to offer.

## F.6 RESERVOIR CASE STUDIES

### F.6.1 NEW DON PEDRO

#### F.6.1.1 Introduction

New Don Pedro (NDP) is essentially a dual-purpose reservoir: outflows are determined by irrigation requirements from April to September, and by demands

for peak hydropower generation during the rest of the year. However, NDP's large turbine discharge capacity enables its managers to make practically all irrigation releases through the hydroelectric plant. In general, NDP's design parameters are fully adequate for management requirements; there has been no spillage since NDP's construction in 1971, and the storage capacity of 2,030,000 acre-feet is more than twice annual irrigation requirements.

NDP is located on the Tuolumne River in the northern San Joaquin Basin; it drains the area around Yosemite National Park, and its high maximum basin elevations are characteristic of the Southern Sierras. The variability of inflows to NDP is reduced by upstream storage of 668,000 acre-feet, concentrated in Hetch Hetchy Reservoir (369,100 AF) and Cherry Lake (268,180 AF). As a result, the peak monthly inflow to the Don Pedro damsite over a five-year period (1961-65) was only 2.16 times mean monthly inflow. For these reasons, Don Pedro is not among the reservoirs with the most critical requirements for current forecast information; however, it may be expected to be more typical of reservoirs located in mid-drainage-system than such large upstream impoundments as Oroville and Dworshak.

#### F.6.1.2 Reservoir Parameters

- (a) Name: New Don Pedro
  - (b) Region: Southern Pacific Slope
  - (c) River basin: Tuolumne
  - (d) Location: La Grange, Cal.,  $37^{\circ} 42.8^1$  x  $120^{\circ} 24.0^1$
  - (e) Purposes: irrigation and hydroelectric
  - (f) Drainage area,  $\text{mi}^2$ : 1530
  - (g) Total storage capacity, acre-ft.: 2,030,000
- Effective hydroelectric storage, acre-ft.: 1,721,000

- (h) Storage ratio\*: 1.1
- (i) Mean annual runoff, acre-ft.: 1,753,000
- (j) Installed hydroelectric capacity, MW: 136.5
- (k) Average annual generation, MWH: 598,400
- (l) Ownership: Turlock and Modesto Irrigation Districts
- (m)  $\frac{\text{5-year peak 30-day inflow}}{\text{mean monthly inflow}} = 2.16$
- (n) Mean annual water content of precipitation in drainage area,  
in.: 20.56
- (o) Mean water content of precipitation,  
October-March, in.: 17.64
- (p) Mean water content of precipitation, Apr.-July, in.: 2.77
- (q) Irrigated acreage: 173,000
- (r) Irrigation acre-footage, annual: 600,000-750,000
- (s) KWH/acre-foot. 210-430 (see Fig. 5.2)
- (t) Mean annual spillage: 0
- (u) Turbine capacity in cfs: 4500 at gauge height 750
- (v) Mean fraction of basin that is snow-covered on April 1: not  
available
- (w) Mean historical error of April 1 runoff forecast: 6.5% (See  
Table 1)
- (x) Current forecast frequency monthly
- (y) Preferred forecast frequency using current management rules:  
semimonthly

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Reservoir capacity  
\*Storage ratio = Mean annual runoff

(z) Months when forecast information requirements are greatest:

Nov-Jan

(aa) Timeliness requirements: 3-4 days (Source: California  
Cooperative Snow Surveys)

#### F.6.1.3 Expected Benefits from Improved Information

##### F.6.1.3.1 Spillage Reduction

The large turbine capacity relative to maximum outflows permits Don Pedro's managers to avoid all spills (see Figure F.6-1). Expected benefits from spillage reduction are therefore zero.

##### F.6.1.3.2 Improved Technical Efficiency

The relationship between increased technical efficiency and hydroelectric benefits is summarized in Figure F.6-3. This function is based on the observed correlation between reservoir storage level and KWH/AF since NDP's construction (see Figure F.6-2). The upper limit on benefits from this source, attainable only if the reservoir were operated just at the flood-control margin year round, is \$950,300 (43,900 MWH: based on increase from mean reservoir elevation in 1974-75). However, this benefit is far from realizable under current management constraints.

This is true for several reasons. First, requirements for irrigation discharges may result in net reservoir drawdowns and thereby reduced technical efficiency. Second, operation of the reservoir at flood-control capacity runs the risk of spillage if there are large unanticipated inflows from precipitation or snowmelt. Third, the seasonal pattern of inflows (approximately 70% of annual runoff is derived from snowmelt) requires that the reservoir be drawn down in Winter to accomodate peak Spring runoff. Fourth, daily

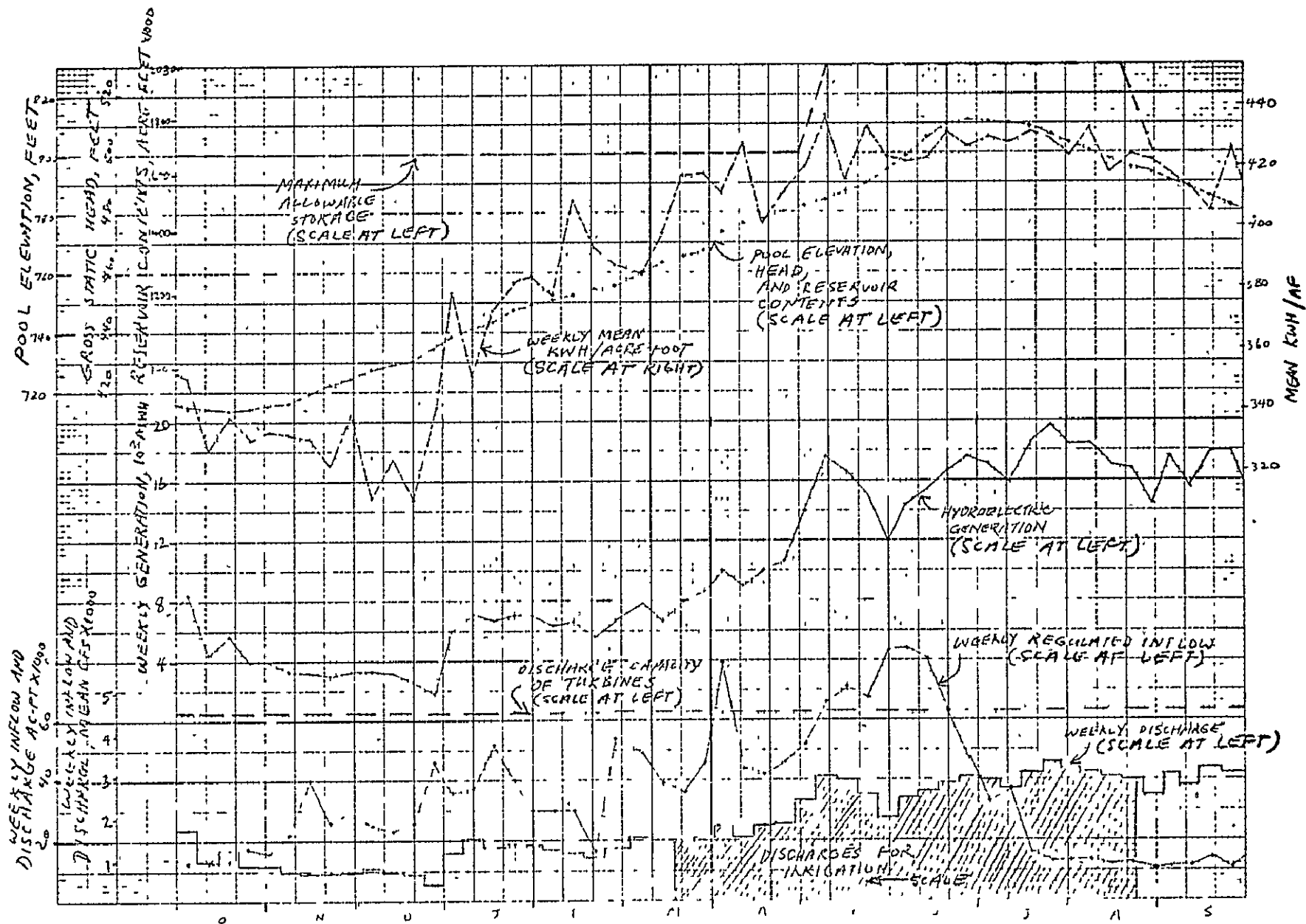


Fig. F.6.1 HYDROGRAPH OF NEW DON PEDRO RESERVOIR, WATER YEAR 1974

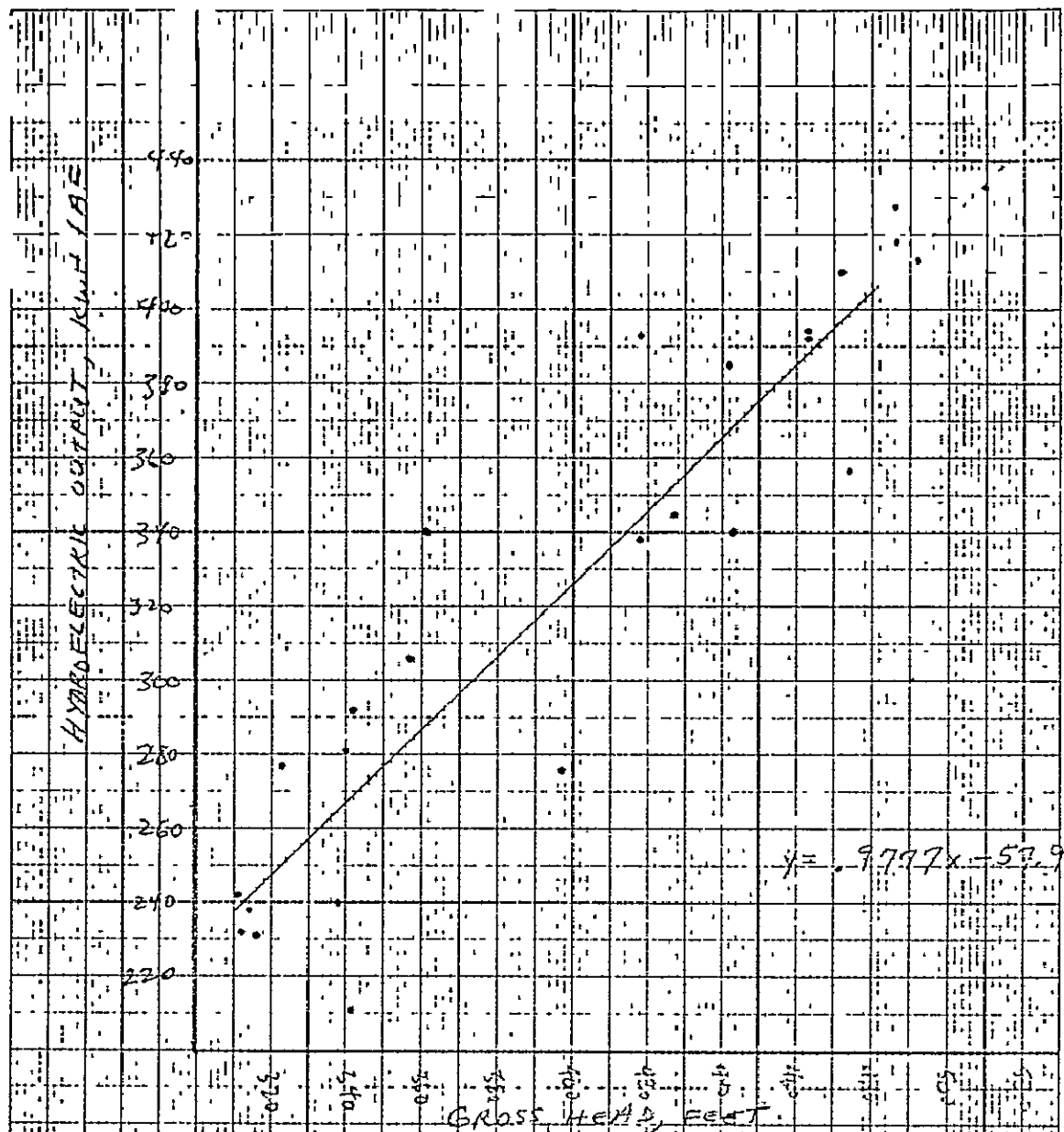
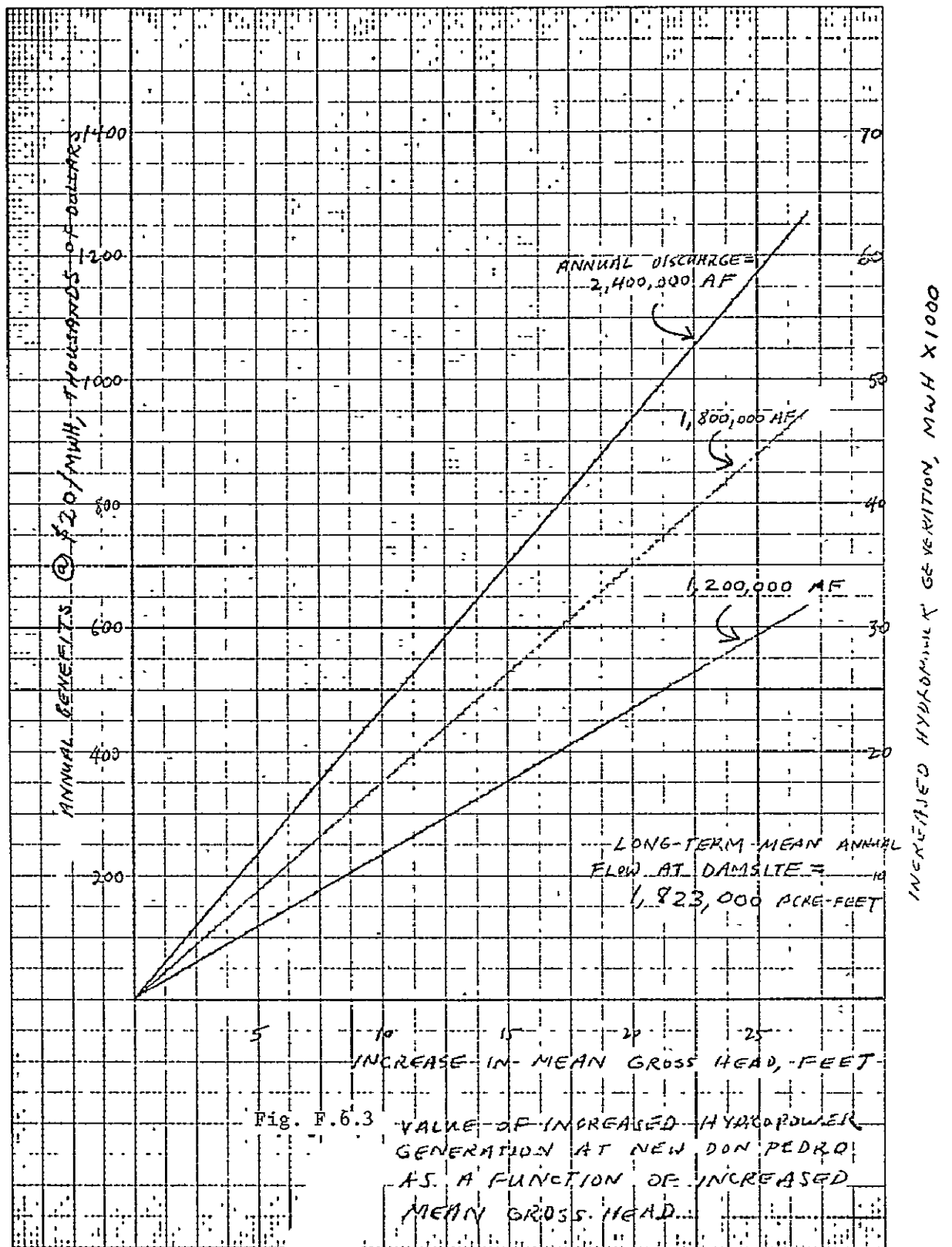


Fig. F.6.2 EFFICIENCY OF HYDROPOWER GENERATION  
 AS A FUNCTION OF GROSS HEAD  
 BASED ON DATA FROM NEW DAM  
 PEPRA DAM AND PULASKI DAM  
 SOURCE: U.S. ARMY CORPS OF ENGINEERS



requirements for peak generation make it necessary to operate the hydroelectric plants even when reservoir storage is below optimal levels.

The last point is true because there is often a tradeoff between technical and economic efficiency. Generally speaking, economic efficiency is served by generating hydropower at those times when the cost of electricity from other sources is greatest; technical efficiency would be maximized by filling the reservoir to maximum effective head and then operating the plant to pass net inflows as they occur. A technically efficient plant would generate most of its annual hydropower during the Spring months, when inflows are greatest, leaving peak power requirements at other times to be met by thermal generation. However, the resulting costs would be substantial. The Turlock Irrigation District, which distributes most of NDP's power, purchases additional power as required from San Francisco's Hetch Hetchy plant. (The Pacific Gas and Electric Company provides a backup). In addition to a base price of \$3.75/MWH, TID pays \$1,570 per month for each additional megawatt of peak generation capacity contracted for. The latter is a charge for peak load rather than total generation; it applies whether the system's peak requirement of, say, 25 megawatts is sustained for one hour or 720 during the month. In an extreme case, therefore, TID might pay \$1,573.75 for a marginal megawatt-hour that could have been supplied, at a small sacrifice in technical efficiency, by the hydroelectric plant. Rather than sustaining such costs, the reservoir managers rely on hydroelectric generation for peak demand whenever possible, whether or not this reduces the mean technical efficiency of the plant.

For these reasons, significant seasonal fluctuations of reservoir storage, and hence of technical efficiency, are unavoidable. The extent to which



these fluctuations can be reduced by improved late season forecasts of snow-melt runoff depends, among other things, on the timing of significant management decisions and the priorities among various reservoir functions.

The management of NDP is oriented around NDP's function as a source of irrigation water for the Turlock and Mottisto Irrigation Districts. Outflows are determined completely by irrigation requirements during the period from approximately April 1 to September 15, and management decisions during the remaining months are constrained by the need to ensure adequate storage at the beginning of the irrigation season. Under current management rules, seasonal storage and drawdown plans are made in November and December and largely completed by early January. This is to enable NDP's managers to make the necessary adjustments in reservoir storage prior to April 1 by means of optimally distributed discharges through the powerplant. As the irrigation season approaches, fewer and fewer hydropower benefits are realizable from improved information. Contracts for supplementary power from outside sources are revised on the first of each month; by March 1, therefore, NDP's power purchases up to the beginning of the irrigation season are fully committed. In fact, few major changes in management plans are made after January in most years. This is made possible both by NDP's large storage capacity and by its location downstream from impoundments which limit flow variability. For these reasons, and because satellite imagery is useful primarily for late-season forecasting, there are no well-confirmed benefits to technical efficiency to be expected from the use of satellite-derived information at NDP under current management constraints.

#### F.6.1.3.3 Improvements in Economic Efficiency

Outside the irrigation season, practically all of NDP's hydroelectric generation is peak generation (defined here as generation between 6 a.m. and 11 p.m.). During the irrigation season, off-peak power is generated only as a by-product of discharges mandated by downstream water requirements. There are therefore zero expected benefits from an improvement in the ratio of peak generation to off-peak generation.

#### F.6.1.3.4 Flood-Control Benefits

The predominance of regulated over unregulated inflows at NDP, together with NDP's large storage capacity, has the effect of reducing flood-control risks to an almost negligible level. The peak monthly inflow over a five-year period at the Don Pedro damsite was only a little more than twice mean monthly flow, and spillage has been avoided altogether (see above). The 30-foot (330,000 acre-foot) flood-control margin which is left unfilled between September and April therefore appears to be more than adequate. Hydroelectric benefits from improved technical efficiency would result from a reduction in this margin (see Figure F.6-3). It should be noted, however, that little reduction in the September-April flood-control margin could be justified by improved snowmelt runoff forecasts (the snow melt runoff season used by the California Cooperative Snow Surveys for forecast purposes at NDP is 1 April-31 July).

#### F.6.1.3.5 Irrigation Benefits

NDP's primary function is irrigation. NDP supplies most of the 800,000-900,000 acre-feet of irrigation water used on 173,000 irrigated acres in the Turlock and Modesto Irrigation Districts. However, Don Pedro's large storage capacity (2.7-3.4 times annual irrigation discharge) enables its managers to compensate

for most runoff forecast errors by moderate reservoir drawdowns (the largest April 1 overestimate of April-July runoff since NDP's completion has been 36,000 acre-feet, or 1.8% of reservoir capacity. See Table F.6-1). The effect of forecast errors can also be cushioned by pumpage from ground water. This source accounts for between 60,000 and 200,000 acre-feet per year of Turlock Irrigation District's irrigation-water supply (Turlock uses about 2/3 of NDP's total irrigation discharge). The amount of irrigated acreage does not fluctuate significantly from year to year.

Because short-term fluctuations in runoff are well-compensated by these factors, NDP's managers estimate that major benefits to irrigation could result from improved forecasts only if accurate long-term runoff predictions were available. These do not appear to be obtainable from improved snow areal extent measurements.

#### F.6.1.3.6 Miscellaneous Benefits

New Don Pedro is not managed for recreation or nevigation, and few benefits could therefore be expected to accrue to these functions from improved forecasts.

### F.6.2 SHASTA

#### F.6.2.1 Introduction

Shasta is the largest and most important reservoir in California's Central Valley Project, which provides irrigation water, hydropower, flood control and other benefits to a large part of the Sacramento Basin. Though there are numerous small upstream impoundments, these have an aggregate storage equal to only about 6.5% of Shasta's mean annual runoff. (Upstream storage = 362,000 AF, Shasta's mean annual runoff = 5, 583,000.) Approximately 65%

Table F.6-1. Tuolumne River Inflow to Don Pedro:  
Forecasts of April-July Runoff in 1,000 Acre-Feet

Year	April Forecast	% Error	May Forecast	% Error	June Forecast	% Error	Actual Runoff
1971	1,020	- 3.4	900	-14.8	1,040	- 1.5	1,056
1972	650	-10.0	730	1.1	680	- 5.8	722
1973	1,450	2.5	1,310	- 7.4	1,240	-12.3	1,414
1974	1,300	- 5.9	1,440	4.3	1,350	- 2.2	1,381
1975	1,330	-10.7	1,550	4.0	1,460	- 2.0	1,490
Mean (abs. values)		6.50		5.72		4.76	1,212.6

Source: A.J. Brown (Chief, Snow Surveys Branch, California Department of Water Resources), personal communication, August 29, 1975.

of Shasta's basin lies below 4,000 feet and 97% lies below 7,000; because of these relatively low elevations, Shasta's basin has significant snow-cover for only a few months (December-April) and most of Shasta's runoff is derived from rainfall. Nevertheless, snowmelt is a significant source of runoff, and Shasta's managers use data from snow courses in the equation used to predict Spring runoff.

Since Shasta is managed in coordination with other reservoirs in the Central Valley Project, it is difficult to allocate benefits between Shasta and the rest of the system. However, since Shasta's usable storage amounts to approximately 50.4% of the total usable storage of all thirteen reservoirs in the CVP, optimization of Shasta's operations is the most important element in assuring the efficient operation of the system as a whole. (CVP, p. 10)

#### F.6.2.2 Reservoir Parameters

- (a) Name: Shasta
- (b) Region: Southern Pacific Slope
- (c) River Basin: Sacramento
- (d) Location: Redding, California -  $40^{\circ}42.81' \times 122^{\circ}24.71'$
- (e) Purposes: Irrigation, hydroelectric, flood control, navigation, fish and wildlife management, recreation, downstream salinity control
- (f) Drainage area,  $\text{mi}^2$ : 6.665
- (g) Total storage capacity, acre-ft.: 4,492,600  
Effective hydroelectric storage, acre-ft: 4,050,000
- (h) Storage ratio: .8
- (i) Mean annual runoff, acre-ft.: 5,583,000 (1922-74)
- (j) Installed hydroelectric capacity, kw: 420,310

- (k) Average annual generation,  $10^3$ kwh: 1,727,800
- (l) Ownership of dam or reservoir: Bureau of Reclamation
- (m) Five year peak 30-day increase in reservoir contents  
                                     Mean monthly inflow  
       = 2.41
- (n) Mean annual water content of precipitation in drainage area,  
       in.: 39.52
- (o) Mean water content of precipitation, Oct.-March, in.: 33.31
- (p) Mean water content of precipitation, Apr.-July, in.: 5.78
- (q) Irrigated acreage: 3,757,000\*
- (r) Irrigation acre-footage, annual: 5,070,000\*\*
- (s) KWH/AF: Up to 500
- (t) Mean annual spillage: 964,000 AF (1970-75)
- (u) Turbine capacity in cfs: 14,000
- (v) Mean fraction of basin that is snow-covered in April 1: Not  
       available
- (w) Mean historical error of April 1 runoff forecast: Approximately  
       10%
- (x) Current forecast frequency: Monthly
- (y) Preferred forecast frequency using current management rules: Two  
       weeks for annual runoff forecasts; real-time for flood forecasting

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\* This figure represents the total irrigable acreage in the Central Valley Project, of which Shasta is the largest single element.

\*\*This figure represents the mean total annual acre-footage supplied by the Sacramento River division of the Central Valley Project. A prorated estimate of Shasta's share of this figure, based on mean inflows to Shasta, Trinity and Folsom reservoirs and to the Sacramento River from unregulated tributaries, is 40% or 2,270,000 acre-feet. However, this figure is subject to large fluctuations from year to year. (WSP1931 and MAC)

(z) Months when forecast information requirements are greatest:

Approx. Feb.-May\*\*\*

(aa) Timeliness requirements: 3-4 days

### F.6.2.3 Expected Benefits from Improved Information

#### F.6.2.3.1 Spillage Reduction

Though Shasta spilled an average of 964,000 acre-feet of water per year in 1970-75, its managers assert that all spillage resulted from precipitation rather than snowmelt. Improved snowpack information therefore is not expected to result in significant benefits from this source.

#### F.6.2.3.2 Improved Technical Efficiency

The approximate relationship between hydroelectric benefits and improved technical efficiency at Shasta is summarized in Figure F.6-4.\* This function is based on the assumption that, in the reservoir's normal operating range, technical efficiency (i.e., kwh/AF) is approximated by a linear function of gross head with origin zero (see, e.g., Fig. F.6-2). It can be seen from Figure F.6-4 that an increase in mean gross head of 13 feet would result in increased generation of 73,400 MWH, for a benefit of \$1,460,000 at \$20/MWH. 13 feet is the mean difference between the reservoir's peak annual gauge height and its storage capacity. For several reasons, only a small fraction of this amount is potentially realizable by improved snow surveys at Shasta (See discussion of technical efficiency at New Don Pedro).

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\*\*\* Based on current forecasting practices.

\*This function is extrapolated from Shasta's peak generation and rated gross head. Historical data for a regression equation linking these variables was unavailable to the authors of this report.

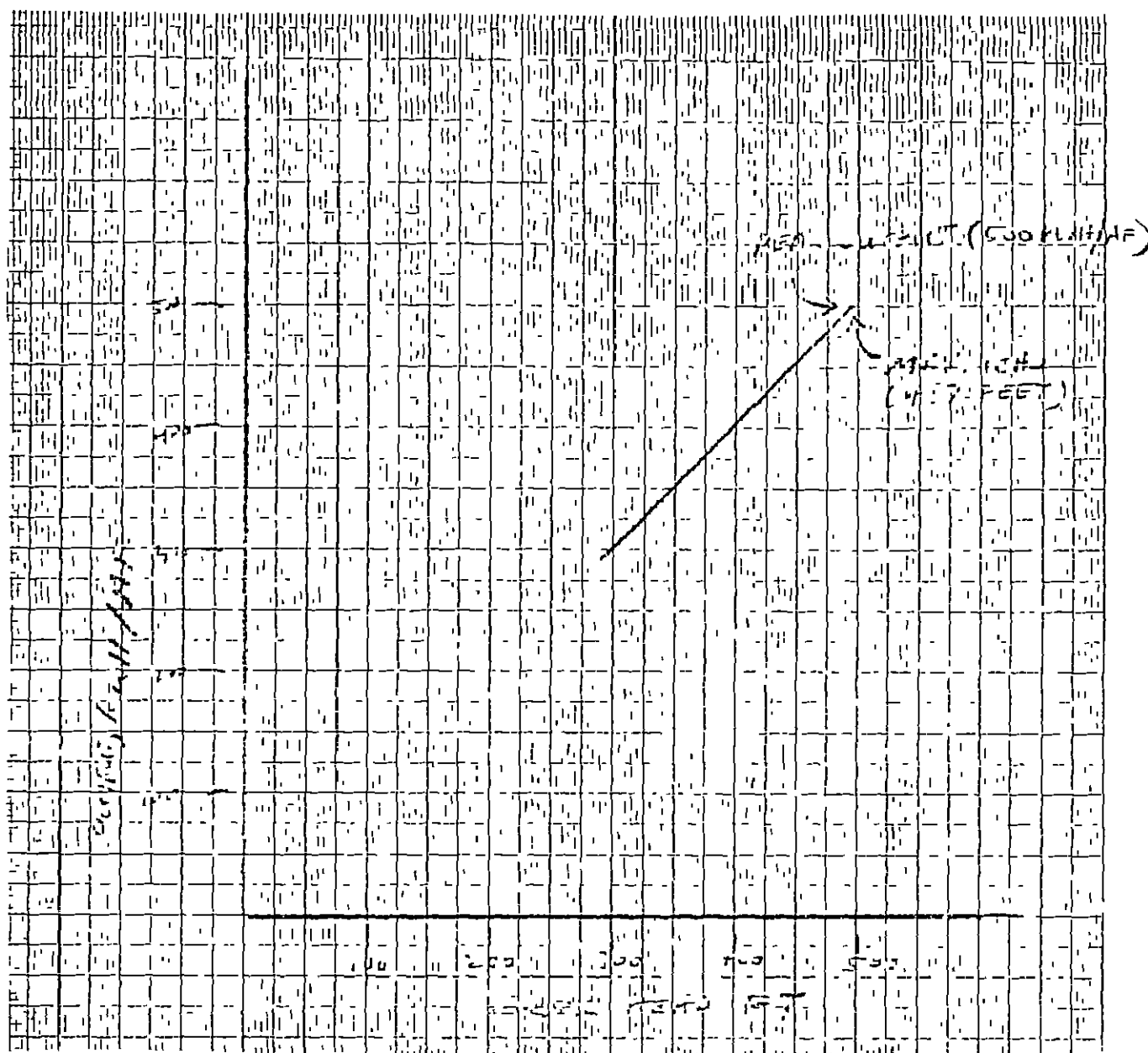


Figure F.6-4 Approximate Relationship Between  
Output and Head at Shasta

Sources: Federal Power Commission, Hydroelectric Power  
Resources of the United States, Washington,  
1972, p. 96.

M.A. Catino (Bureau of Reclamation, Sacramento),  
Letter of August 1, 1975.



In general, despite Shasta's large annual generation, power production at this reservoir is subject to prior constraints set by other reservoir functions during most of the year. (CVP, p. 10) "Except in very wet years the daily power schedules...are based on water requirements of the (Central Valley) Project....During the months of November through March, flood control objectives normally dictate the operation of both Trinity and Shasta Lakes. From April through August, irrigation and salinity (regulation) control the quantity of releases required from both reservoirs. Late summer and fall demands are primarily for fish protection and enhancement and evacuation of flood reservation space if required. ...Both Shasta and Trinity Lakes must be drawn down to maximum flood control reservation by late November, eliminating the possibility of maximizing carryover storage on a year-to-year basis. ...In wet years, excess water is available which can be released on a basis of maximum power system benefits." (MAC, p. 2) It follows from this policy that in most years, a significantly increased mean reservoir level is not to be expected from improved information except as a by-product of reduced discharges for other purposes such as irrigation and flood control. This might happen as a consequence of a reduction in positive forecast error, since Shasta's managers will release less water for irrigation in a year that is expected to be dry than in a wet year. On the other hand, a reduction in negative forecast error would be expected to reduce mean effective head, since the reservoir managers, knowing that there will be water available for marginal irrigation requirements, will increase releases for that purpose. If improved information serves to reduce positive and negative forecast errors with equal effectiveness, benefits to hydropower in years of reduced positive error will generally be counter-balanced by disbenefits in years of reduced negative forecast error. Similar remarks apply to the relationship

between flood-control discharges and hydropower generation, with the qualification that, since the flooding risk at Shasta stems primarily from rainfall runoff, improved snow surveys would not be expected to have a major impact either way on flood control policies. (GHB)

For these reasons, significant benefits from increased mean effective head at Shasta are not to be expected as a by-product of improved management of discharges for irrigation and flood control. One would expect such benefits, if at all, in those wetter-than-usual years when hydropower maximization can be pursued independently of water requirements for other purposes. Since peak flows generally result from rainfall, the impact of snow surveys on benefits is difficult to estimate. However, the following calculation establishes the order of magnitude of possible benefits. A reduction of positive February-July forecast error from 10% to 7.5% in a year in which Feb., March, April, May, June and July inflows were each at the third quartile could result in additional usable storage of up to 105,000 acre-feet, assuming that the entire amount of the forecast error reduction resulted in increased storage and hence increased head.\* At the mean April 1 storage level of 3,670,000 acre-feet (based on 1961-65 data), this additional storage would raise the reservoir's mean elevation by approximately four feet. (WSP1931, p. 74) If this increment in head were maintained from March 1 until the beginning of the next flood control season (Oct. 1) (CVP, p. 17) and monthly flows remained at the third quartile level, the resulting additional generation would be approximately  $3,682,000 \text{ AF} \times .00103 \text{ MWH/AF/ft} \times 3.97 \text{ feet} = 15,800 \text{ MWH}$  for a value of \$316,000 at \$20/megawatt hour. However, this benefit is realizable, if at all, only in those years of unusually heavy runoff in which there is a

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\*Data on Shasta's historical runoff pattern are found in CVP, pp. 28-29.

positive forecast error (When there is a negative forecast error, reservoir storage, and hence effective head, is generally higher than it would have been with perfect information). If this benefit is realizable every second year in which flows are above the median, and negative forecast errors occur as often as positive errors, the maximum undiscounted annual benefit to be expected from this source is approximately  $\$316,000 \times .5 \times .5 \times .5 = \$39,500$ .

This estimate is subject to a number of caveats; for example, if benefits are realizable in every above-average runoff year in which there are positive forecast errors, the resulting estimate will be somewhat less than twice that given above, since the relevant mean runoff figures will be less but the frequency of benefits will be greater. If Feb.-July forecast error can be reduced from 10% to 5%, rather than from 10% to 7.5%, then benefits will be doubled. However, neither of these proposed assumptions is consistent with the available evidence on Shasta. The frequency of benefits cannot be expected to be greater than that assumed above, because only in very wet years is water available for independent maximization of hydropower. (MAC, p. 3)

The reduction in forecast error by the use of satellite data cannot be assumed to be greater than 25%, and it is probably considerably less, because such a large proportion of Spring runoff is in the form of rainfall. Since there is very little snowpack remaining after April 30, a reduction of Feb.-July error from 10% to 7.5% by means of improved snow-cover observations requires a reduction in Feb.-April error, other things being equal, from 10% to approximately 6.4% (assuming monthly runoff at the third quartile level). A reduction in Feb.-July error from 10% to 8.75%, corresponding to a reduction in Feb.-April error from 10% to about 8.2%, would yield undiscounted annual benefits of approximately \$20,000.

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\*MAC, p. 3

#### F.6.2.3.3 Improvements in Economic Efficiency

Under the terms of a contract with Pacific Gas and Electric Co., which purchases Shasta's power output, Shasta is operated primarily as a producer of peak power. (GVP, pp. 11-12.) The information available to us does not provide grounds for assuming that the ratio to peak to off-peak generation could be further increased by the use of satellite-derived snow-cover measurements.

#### F.6.2.3.4 Flood Control Benefits

As outlined in sections F.6.2.1 and F.6.2.3.2 above, the flooding risks at Shasta are generally the result of rainfall rather than snowmelt runoff. Improved snow-cover observations are therefore unlikely to result in benefits from this source.

#### F.6.2.3.5 Irrigation Benefits

Shasta is operated largely as a source of irrigation water for California's northern Central Valley. Mean annual discharges from Shasta for irrigation, estimated on a prorata basis, exceed 2,000,000 acre-feet/year.\* The snowmelt runoff season at Shasta (which lasts through April) overlaps with the planting seasons of a number of important crops in California's northern Central Valley, including corn, oats, rice and spring sugarbeets. (USD, p. 47.) It is likely that improved runoff forecast information would result in benefits in these areas. For example, a decrease in Feb.-July forecast error from 10% to 7.5% in a year in which each of the months Feb.-July had median runoff might result in the more efficient allocation of up to 72,700 acre-feet of irrigation water. If this water would otherwise have been unavailable for irrigation, the resulting benefit in that year amounts to approximately \$290,000 at \$4/acre-foot.\*\* This figure may be regarded as an upper limit on benefits from this source, for the following reasons:

(1) As discussed in section F.6.2.3.2, above, a reduction in runoff forecast

\*See section 6.2.2, item (r), note, above.

\*\*\$4/acre-foot is the approximate mean price of irrigation water in one irrigation district in Central California. Source: Turlock Irrigation District, Turlock, Cal.

error of this magnitude is probably not attainable from improved snowcover observations because of the predominance of rainfall in total runoff; (2) Since the greater part of the irrigation season occurs after the end of the snowmelt season at Shasta, it is unrealistic to assume that water not used for irrigation during the snowmelt season will be unavailable for use later.

#### F.6.2.3.6 Miscellaneous Benefits

Significantly improved Spring runoff forecasts might ease discharge allocation for navigation, salinity control and fish and wildlife protection. However, except in extreme cases, these functions do not directly bear the costs of misforecasts or derive benefits from improved forecasts, since discharges for these purposes are mandated by legislation or long-term management policies. That is, these functions set constraints within which management must operate. Measurable benefits from improved information therefore accrue only to those functions, such as irrigation and hydropower, which can be supplied with variable amounts of water depending upon conditions and available data.

### F.6.3 YELLOWTAIL

#### F.6.3.1 Introduction

Yellowtail is a relatively large upstream reservoir in the Missouri system. It controls drainage from the Bighorn Basin in Wyoming, and has significant runoff from both rainfall and snowmelt. Though it is upstream of such large Missouri reservoirs as Fort Peck, Sakakawea and Oahe, Yellowtail is below a number of smaller flood-control dams, with the result that its inflows are moderated significantly.

#### F.6.3.2 Reservoir Parameters

- (a) Name: Yellowtail (Bighorn Lake)
- (b) Region: Upper Missouri Basin
- (c) River Basin: Bighorn
- (d) Location: Hardin, Montana,  $45^{\circ}19.0^1$  x  $107^{\circ}57.0^1$
- (e) Purposes: Irrigation, hydroelectric, flood control
- (f) Drainage area,  $\text{mi}^2$ : 19,600
- (g) Total storage capacity, acre-ft.: 1,375,000  
Effective hydroelectric storage, acre-ft.: 614,000
- (h) Storage ratio: .5
- (i) Mean annual runoff, acre-ft.: 2,650,000
- (j) Installed hydroelectric capacity, MW: 250
- (k) Average annual generation, MWH: 910,000
- (l) Ownership: Bureau of Reclamation
- (m) 
$$\frac{\text{5-year peak 30-day inflow}}{\text{mean monthly inflow}} = 3.94$$
- (n) Mean annual water content of precipitation in drainage area, in.: 9.66
- (o) Mean water content of precipitation, October-March, in.: 2.93
- (p) Mean water content of precipitation, April-July, in.: 5.16
- (q) Irrigated acreage: 43,000
- (r) KWH/AF: 325-422 (approx.) (WY 1970-74)
- (s) Mean annual spillage, acre-feet: 39,000 (1970-74)
- (t) Turbine capacity in cfs: 8400-9000 (approx.)
- (u) Mean historical error of April 1 runoff forecast:  
6.7% (WY 1970-74); 16.2% (WY 1965-74)
- (v) Current forecast frequency: monthly
- (w) Months when forecast information requirements are greatest:  
April-July

### F.6.3.3 Expected Benefits from Improved Information

#### F.6.3.3.1 Spillage Reduction

Yellowtail spilled a total of 193,338 acre-feet of water during the five year period from October 1969 to September 1974, practically all of it in June and July of 1970 and June and July of 1974. If all this spillage had passed through the generators at mean effective head, it would have produced approximately 74,000 megawatt hours of electricity, worth \$1,480,000 at \$20/MWH, for an undiscounted mean annual benefit of \$296,000.

In each case, the major cause of spillage was an unusual snowmelt pattern combined with uncertainty about the size of the remaining snowpack. In both years, snowmelt runoff was well below expected levels in April, May, and part of June, followed by rapid depletion of the snowpack and high runoff levels in late June and July. Because of desirability of filling the reservoir by the end of the runoff season, the reservoir was allowed to reach a higher storage level by mid-June than would have been the case if it had been known that a rapidly melting snowpack remained in the basin.

The rate of snowmelt, which is primarily a function of temperature, is at least as important for spillage avoidance at Yellowtail as is the total quantity of runoff. Given the current accuracy of seasonal snowmelt forecasts, the primary supplementary information requirement is for accurate temperature forecasts. Late-season snow areal extent information would also be of use for forecast updating in years of unusual melt patterns.\*

If 25% of 1969-74 spillage could have been avoided by improved late-season areal extent information, the mean annual increase in hydropower generation would have been about 3,700 MWH at mean effective head, for a mean annual benefit of \$74,000.

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\*Information in this and the preceding paragraph is based on conversations with Bryan Edwards, Chief, Reservoir Regulation Branch, Bureau of Reclamation, Billings, Montana, Sept. 15, 1975.

#### F.6.3.3.2 Increased Technical Efficiency

An increase of one foot in mean effective head at Yellowtail, sustained for a full year, would yield additional hydropower, in a normal runoff year, of

$$2,650,000 \text{ AF} \times .00108181 \text{ MWH/AF/ft.} \times 1 \text{ ft.} = 2,867 \text{ MWH.}$$

This additional generation would have a value of approximately \$57,000 at \$20/MWH.

It is unlikely that significant benefits from this source are available at Yellowtail, however. Perhaps because most of its inflows are subject to prior regulation, seasonal fluctuations in Yellowtail's storage level are limited to a relatively narrow range. The five-year mean gauge height of 3623.6 feet is only 21 feet below peak storage for the period, with a standard deviation of 13.2 feet. Furthermore, the amount of water required to fill the reservoir an additional foot in depth is only 9,100 acre-feet at mean storage level, or 4.1% of mean monthly runoff. There thus would appear to be ample capability in most years for late-season adjustment of reservoir storage within the limits permitted by current reservoir management policies. Losses of hydropower generation as a result of unnecessary drawdowns, whether due to overforecasts or other causes, do not in general result in sacrifices of efficiency for the rest of the year.\*\* Improved snowmelt forecast information is therefore not expected to result in large increases of mean effective head at Yellowtail. (For more extensive discussion of an analogous case, see the discussion of technical efficiency in the chapter on Dworshak, below).

#### F.6.3.3.3 Improved Economic Efficiency

According to Yellowtail's managers, "The method of plant operation and the manner of marketing the energy as part of an integrated power system makes it impossible

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\*This coefficient, based on a regression of MWH/AF against reservoir gauge height at Yellowtail over a period of five years, applies in Yellowtail's normal operating range only.

\*\*Telephone conversation with Bryan Edwards, Bureau of Reclamation, Billings, Montana, September 15, 1975.



to tell what portion of the Yellowtail generation is used for peaking."\* It is therefore not possible to evaluate the possible benefits to economic efficiency which might result from improved forecast information.

#### F.6.3.3.4 Flood-control Benefits

In general, upstream regulation reduces inflow variability to the point that the risk of flooding at Yellowtail is minimal. However, Yellowtail's discharges have reached (but not exceeded) the downstream channel capacity on one occasion in the eight years of the dam's full operation; this was in July, 1967, when heavy late season precipitation resulted in peak runoff at a time when the reservoir was already near capacity. The April-July forecast in that year was 41% low. However, the primary source of error was unanticipated rainfall rather than snowmelt runoff. In 1967, this factor was compounded by strong pressures on management to fill the reservoir, the construction of which had just been completed.

The available data are not sufficient to support generalizations about the probability that an analogous set of circumstances will arise in the future. Therefore, though there may be flood control benefits at Yellowtail from improved snow surveys, it is not possible to quantify them on the basis of available information.

#### F.6.3.3.5 Irrigation Benefits

Approximately 43,000 acres are irrigated by diversions from the Bighorn river below Yellowtail. These are adequately supplied with water from Yellowtail's normal power releases, and irrigation requirements do not set constraints on Yellowtail's operations. In general, there are adequate water supplies for this function without deliberate management intervention. Expected benefits to irrigation from improved forecasts are therefore zero.

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\*Letter from James A. Rawlings, Regional Supervisor, Division of Water and Land, Bureau of Reclamation, Billings, Montana, July 25, 1975.

#### F.6.3.3.6 Miscellaneous Benefits

Yellowtail's primary functions are hydroelectric generation, irrigation, and flood control, and there is no information available to us which indicates that any other functions would benefit significantly from improved forecast information.

#### F.6.4 DWORSHAK

##### F.6.4.1 Introduction

Dworshak is a large, multipurpose, upstream reservoir located on the Clearwater River in northern Idaho. Between 80% and 90% of Dworshak's inflow is derived from snowmelt, and these inflows are practically unregulated by other impoundments. In these respects Dworshak is a very interesting prima facie candidate for remote-sensing applicability. Dworshak has been selected as the object of a case study under NASA's snowcover measurement Applications Systems Verification Test, but research has been hampered by Dworshak's generally heavy cloud cover during the snowmelt season. Dworshak's basin is mountainous and heavily forested. This makes ground-based snowcover observations more difficult than they might otherwise be, and also complicates the interpretation of satellite imagery. Dworshak's current monthly forecasting equation is supplemented by simulations by the Army Corps of Engineers' Streamflow Synthesis and Reservoir Regulation model, which integrates snowcover, precipitation, temperature, and streamflow information into a near-real-time model of basin hydrology.

Because Dworshak was completed only in 1971, historical data on reservoir operations since first filling are limited. However, records of forecast and actual runoff are available for a thirty-year period. These data sources are therefore used in combination whenever possible.

#### F.6.4.2 Reservoir Parameters

- (a) Name: Dworshak
- (b) Region: Snake Drainage Region
- (c) River Basin: N.F. Clearwater
- (d) Location: Orofino, Idaho, 116° 15' x 46° 35'
- (e) Purposes: Flood control, navigation,  
hydroelectric, recreation
- (f) Drainage area, mi<sup>2</sup> 2440
- (g) Total storage capacity, acre-ft. 3,453,000  
Effective hydroelectric storage, acre-ft: 2,000,000
- ✓(h) Storage ratio: .8
- (i) Mean annual runoff, acre-ft.: 4,133,000
- (j) Installed hydroelectric capacity, kw: 1,060,000
- (k) Average annual generation, 10<sup>3</sup> kwh: 1,120,000
- (l) Ownership of dam or reservoir: Army Corps of  
Engineers
- (m) KWH/AF: up to 565
- (n) Mean annual spillage:
- (o) Turbine capacity, cfs: 9,700\*
- (p) Mean fraction of basin that is snow-covered on  
April 1: ~ 73%
- (q) Mean historical error of April 1 forecast: 7.6%
- (r) Current forecast frequency: Monthly \*\*

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\*Based on historical data. Note: spillage often occurs on days when mean turbine discharge is much less than this figure.

\*\*With supplementary information from the Army Corps of Engineers' Streamflow Synthesis and Reservoir Regulation forecasting model, which operates in near-real-time (cf.SSA)

- (s) Preferred forecast frequency using current management rules: Not available
- (t) Months when forecast information requirements are greatest: March-June

F.6.4.3 Expected Benefits From Improved Information

F.6.4.3.1 Spillage Reduction

Total spillage at Dworshak in the two-year period from April 1973 to March 1975 was 3,732,000 acre-feet, for an annual average of 1,866,000 acre-feet.\*\* Because of the short data base, of course, this figure is only a rough approximation of what may be expected over a longer term.

Spillage may result either from overforecasts or underforecasts. It results from overforecasts when managers draw down the reservoir through the spillways in order to allow increased flood-control space, space which remains unfilled because actual inflows are less than predicted inflows. Spillage due to underforecasts occurs when inadequate reservation space for inflows is allowed, requiring managers to open the spillways to avoid dangerously high reservoir storage or even larger spills later in the season.

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\*Fred A. Limpert, Bonneville Power Administration, remarks at Workshop on Operational Applications of Satellite Snowcover Observations, S. Lake Tahoe, Cal., Aug. 18-20, 1975.

\*\*Figures are given for the April-March period because data for the corresponding water years is not complete.

An approximate upper limit on potential spillage reduction from forecast improvement is set by the aggregate absolute deviation, in acre-feet, of forecasted from actual inflows. For the thirty years for which records are available at Dworshak (1940-1965 and 1971-74), this figure is 6,415,000 acre-feet, for an absolute mean annual forecast deviation of 213,800 acre-feet. Spillage represented 36% of total discharges in 1973-75. It may be assumed that spillage represents a somewhat higher proportion of forecast-error-related discharges than of "normal" discharges. There is insufficient data to determine just what this proportion is, however. If 50% of error-related discharges consist of spillage, compared to 36% of "normal" discharges, potential benefits from a 25% forecast error reduction amount to approximately

$$.25 \times (.5 - .36) \times 213,800 \text{ AF} \times .50667 \text{ MWH/AF}^* = 3791 \text{ MWH} \times$$

$$\$20/\text{MWH} = \$75,800.$$

Given a potential benefit from improved forecasts, it remains to be determined what fraction could be realized by improved snow areal extent data. Mr. Robert Rickle, an Army Corps of Engineers hydrologist with responsibility for Dworshak, estimates that areal extent information is one of the most important missing parameters in the current forecasting model.\*\*

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\*Based on mean effective head, 1973-75, and the following linear regression equation relating KWH/AF to gross head at Dworshak.  $\text{KWH/AF} = 97.8978 + .7123H$

\*\*Telephone conversation with Robert Rickle, Chief, Hydrology Section, Army Corps of Engineers, Walla Walla, Wash. July 15, 1975.

The Army Corps of Engineers' Streamflow Synthesis and Reservoir Regulation (SSARR) model, which Dworshak has begun to use, accepts estimates of areal extent of snowcover as part of its hydrologic simulation routine, but sufficiently reliable data for these estimates has up to now been lacking.

An important feature of the situation at Dworshak, however, is the prevalence of cloud-cover during most of the snowmelt season. This difficulty has so far prevented a pilot study of satellite snowcover data collection at Dworshak, under NASA's snowcover ASVT, from achieving significant results. It therefore appears that, if satellite snowcover observation is to be of use for runoff forecasting at Dworshak and elsewhere in the Pacific Northwest, it will have to have a rather high frequency of coverage to ensure occasional cloud-free imagery. This is true even though the SSARR model is a sufficiently accurate simulator of snowcover depletion that it generally requires only few data points on areal extent during the melt season to achieve usable results.\*

F .6.4.3.2      Increases in Technical Efficiency

The potential benefits from increases in gross generation head at Dworshak may be estimated as follows. This estimation procedure follows closely the procedure followed for other dams in this study.

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\*Information in this paragraph is based on conversations with Fred A. Limpert, of the Bonneville Power Administration, and Robert Rickle, Army Corps of Engineers, Walla Walla, Wash., as well as on Mr. Limpert's remarks at the Workshop on Operation Applications of Satellite Snowcover Observations, at Lake Tahoe, California, August 18-20, 1975 (LIM, RGR)

Assume that Dworshak's listed surface area (16,970 acres) represents the surface area at current mean annual storage. Assume further that its surface area does not change significantly as a result of increments in storage due to reduced forecast error. Then a reduction in positive forecast error of 16,970 AF, if it results in the retention in storage of an additional 16,970 AF of water for 1 year, raises mean reservoir elevation by 1 foot.

The mean positive forecast error in 1940-74 was 7.6%, or 226,000 AF. Under the above assumption, this corresponds to a difference in head of approximately 13.3 feet. For each foot of additional head which is sustained for a year, an additional 2943 MWH, worth \$59,000, can be generated with normal runoff.\* A 25% reduction in positive forecast error, if it were entirely reflected in increased storage, would result in annual benefits of about \$98,000.\*\*

However, most positive forecast errors do not result in sacrifices of storage for the entire year. In a year that is projected to be dry and turns out to be even drier, for example, little incremental flood-control reservation space

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\*The equation of a least-squares regression line relating head to mean KWH/AF for a sample of 24 generation days over a 2-year period at Dworshak is  $KWH/AF = 97.98 + .7123(Head)$ . This equation is valid for Dworshak's normal operating range only.

For a one-foot difference in head with mean annual runoff (4,133,000 AF), we have  $.7123 KWH/AF \times 4133000 AF = 2943000 KWH$   
 $= 2943 MWH \times \$20/MWH = \$58860.$

\*\*Assuming that negative and positive forecast errors occur with equal frequency.

may be unnecessarily evacuated because of imperfect information. On the other hand, in years of unusually heavy projected and actual runoff, when the reservoir must be drawn down to maximum flood-control reservation space in any case, a reduction of positive forecast error may not result in significantly increased head. Most important of all, as the flood-control season ends, it is often possible to fill the reservoir to near-maximum levels despite large forecast errors. In 1973, for example, actual April-July runoff was the lowest in 30 years of record, and there was a positive forecast error of 34%. This error was the largest in percentage terms since forecasting began in 1940. Nevertheless, Dworshak's managers succeeded by mid-July in reaching an effective head of 628 feet, or two feet less than capacity, by compensating for forecast errors as the runoff season progressed.

The possibility of such corrections reduces to a small figure the expected economic benefit to be derived from reductions in positive forecast errors. It does not eliminate such benefits altogether. Even if error compensation is possible by the end of the runoff season, there is still a period of several weeks when the reservoir level is lower than it would have been with perfect information.

Assume that 50% of positive forecast errors result in unnecessary drawdowns for an average period of six weeks (This represents the length of time from the onset of maximum flood-control reservation space (May 1) to the midpoint



of the remaining snowmelt runoff season (June 15)). A 25% reduction in positive forecast error, from 7.6% to 5.7%, would result in savings of approximately

$$50\% \times (\text{increase in head}) \times (\text{May 1-June 15 discharge}) \\ \times (\Delta\text{MWH}/\Delta\text{F}/\Delta\text{Head}) \times (\$/\text{MWH}) = \text{dollar benefits}$$

In this case,

$$.5 \times [226,400 \times .25 - 16,970] \times \left( 4,133,000 \times \frac{1.5}{12} \right) \times .00071231 \\ = 600 \text{ MWH} \times 20 = \$12,000$$

in a year with runoff equal to the long-run mean. This assumes that the rate of power generation in May and June is not significantly different from the mean annual generation rate.

Since positive and negative forecast errors occur with approximately equal frequency, the corresponding undiscounted annual benefit is \$6000. This result is overstated in that it assumes that all runoff passes through the turbines; it is understated to the extent that the generation rate in the period May 1-June 15 is higher than average. It is also understated if positive forecast errors cannot be largely compensated by the end of the runoff season. However, the available data does not support the latter assumption.

#### F.6.4.3.3 Increased Economic Efficiency

There are insufficient data to evaluate this parameter for Dworshak's generation. In the case of Dworshak and other Pacific Northwest reservoirs, analysis of this issue is complicated by the fact that most of the electric generation in this region, peak as well as off-peak, is supplied by a large, integrated network of hydroelectric plants throughout the Columbia and Snake River Basins. Individual elements of the system are almost impossible to isolate meaningfully. The system's economic efficiency may be served by an increase in off-peak generation by some of the plants in the network, even though this decreases the revenue accruing to those plants considered singly.

#### F.6.4.3.4 Flood Control Benefits

Potential flood-control benefits at Dworshak are large but difficult to quantify. Serious risks of flooding were present in 1974, when actual April-July runoff was approximately 736,000 acre-feet heavier than predicted. In this case, serious downstream damage was avoided, but the remaining margin of error was dangerously narrow. In the opinion of one of the managers responsible for Dworshak, improved areal extent information might have reduced the flooding risk in this situation;<sup>\*</sup> however, evaluation of this hypothesis, and quantification of the potential benefits

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<sup>\*</sup>RGR, July 15 and July 18, 1975.

involved, would require analyses of stream flow patterns, downstream topography, and reservoir management rules which are beyond the scope of this study.

F.6.4.3.5        Irrigation Benefits

Water supplies in Dworshak's irrigation district are fully sufficient to meet current and projected demands even in below-normal water years. Until this situation changes, the expected benefits from improved information will remain negligible.

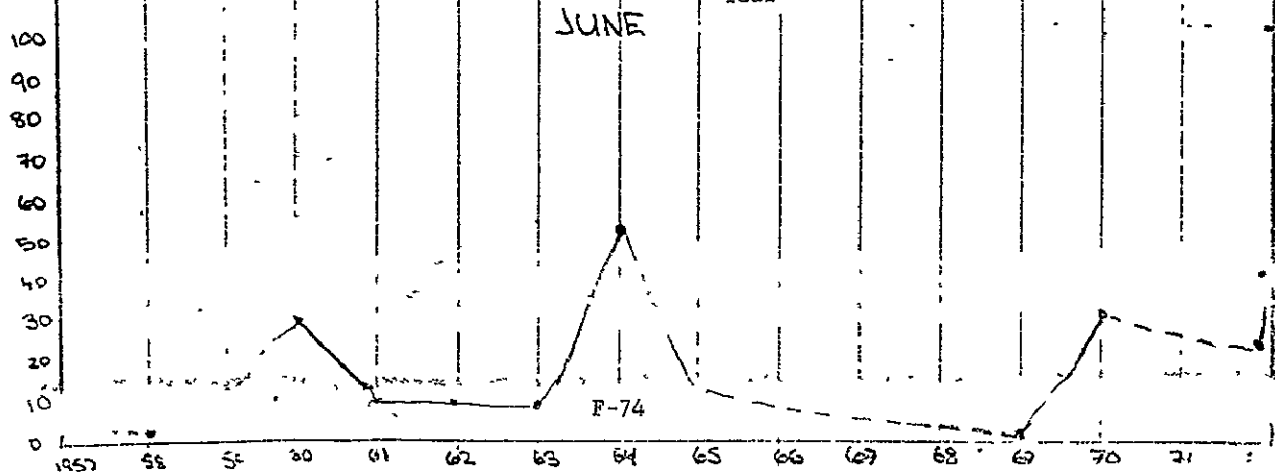
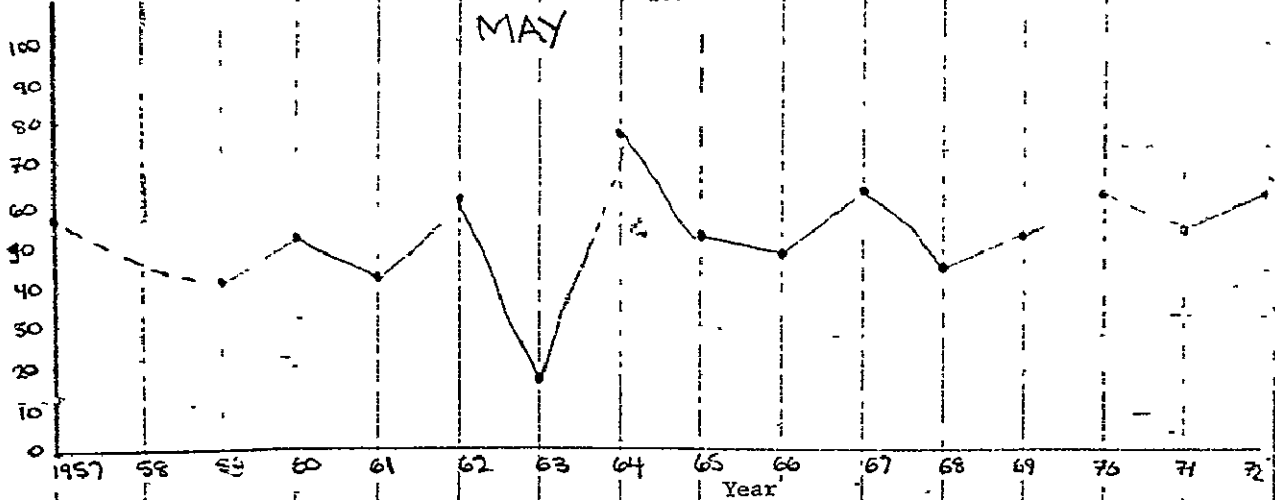
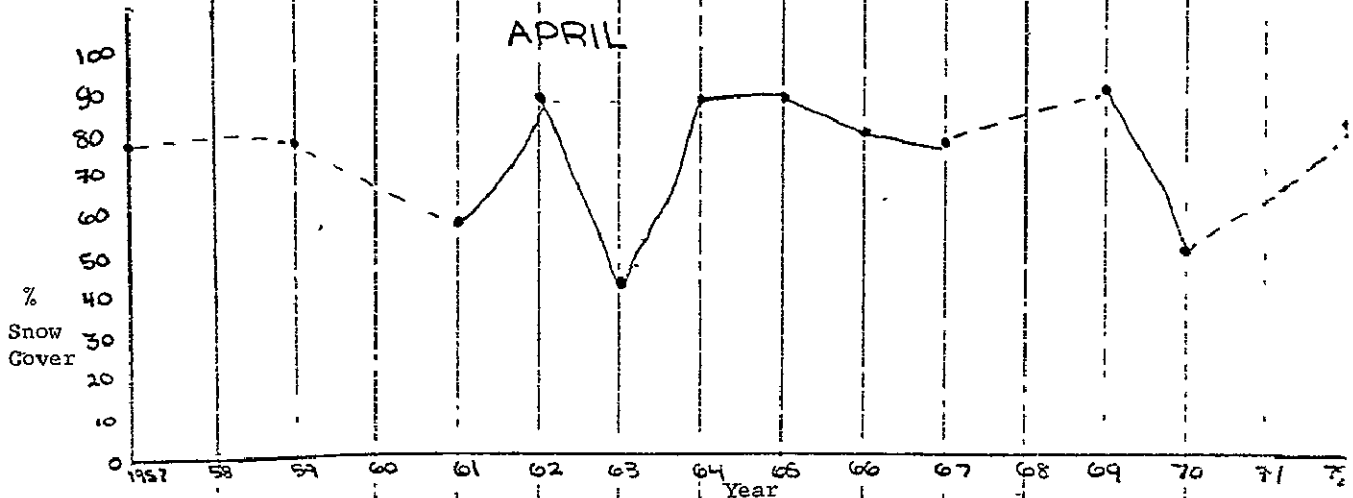
F.6.4.3.6        Other Benefits

Dworshak is also operated for the purposes of navigation and recreation. However, we do not have sufficient information to evaluate the potential benefits of improved information to these functions.

Figure F.6.5

# DWORSHAK Snow Covered Area (%)

Jan-March est 80-100% of basin covered with snow.



## F.6.5 PALISADES

### F.6.5.1 Introduction

Palisades is a large upstream impoundment in the Snake River System, with outflows used for hydroelectric generation, irrigation, and municipal water supply. As part of a cooperative management program with Jackson Lake, which regulates the Snake River headwaters, Palisades also serves flood control and conservation objectives. Like many other reservoirs in the Snake system, Palisades has abundant but highly variable inflows derived largely from snowmelt.

This reservoir is one of the test sites chosen for NASA's Applications Systems Verification Test on the usefulness of satellite-derived snowcover information for runoff forecasting. However, research to date has been hampered by the generally heavy cloud cover which prevails in this basin as in the rest of the Pacific Northwest.

### F.6.5.2 Reservoir Parameters

- (a) Name: Palisades
- (b) Region: Snake Drainage Region
- (c) River Basin: Snake
- (d) Location: Irwin, Idaho,  $43^{\circ}20.1'$  x  $111^{\circ}12'.0^1$
- (e) Purposes: irrigation, hydroelectric, flood control,  
conservation, municipal water supply
- (f) Drainage area,  $\text{mi}^2$ : 5208
- (g) Total storage capacity, AF: 1,402,000  
Effective hydroelectric storage, AF: 1,200,000

- (h) Storage ratio: .3
- (i) Mean annual runoff, AF: 4,700,000
- (j) Installed hydroelectric capacity, kw: 118,750
- (k) Average annual generation, MWH: 610,000
- (l) Ownership of dam: Bureau of Reclamation
- (m) 
$$\frac{\text{Five-year peak 30-day increase in reservoir contents}}{\text{Mean monthly inflow}} = 1.52$$
- (n) Mean annual water content of precipitation in drainage area, in.: 24.38
- (o) Mean water content of precipitation, Oct-March, in.: 14.32
- (p) Mean water content of precipitation, April-July, in.: 7.33
- (q) Irrigated acreage: 650,000
- (r) Mean KWH/AF: 189
- (s) Mean annual spillage, AF: 2,000,000 (1970-74)
- (t) Turbine capacity, cfs: 8025 at rated head
- (u) Mean fraction of basin that is snow-covered on April 1: 100%
- (v) Mean error of April 1 forecast: 6.9% (1970-74)
- (w) Current forecast frequency: Monthly\*

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\*Palisades also makes use of the Army Corps of Engineers' Streamflow Synthesis and Reservoir Regulation Model, which provides daily updates of runoff estimates.

F.6.5.3 Expected Benefits from Improved Information

F.6.5.3.1 Spillage Reduction

Palisades spills large amounts of water even in below-average runoff years. For example, between January, 1970, and December, 1974, mean annual spillage was about 2,000,000 acre-feet; the range was 940,000-2,966,000 acre-feet/yr. Since mean forecast error in this period was the equivalent of 288,000 acre-feet, most of Palisades' spillage in these years could not have been avoided by improved forecasts.

The order of magnitude of potential benefits from spillage reduction may be estimated as follows. Assume that forecast improvement results in reduced spillage in an amount equivalent to 25% of current forecast error. (This would require a greater-than-25% reduction in gross forecast error, since not all forecast error reductions can be expected to result in reduced spillage.) Under this assumption, an additional  $288,000 \times .25 = 72,000$  acre-feet of water will be available for hydropower generation.

At mean technical efficiency of 189 KWH/AF, the resulting output is

$$.189 \text{ MWH/AF} \times 72,000 \text{ AF} = 13.600 \text{ MWH}$$

which would be worth \$272,000 at \$20/MWH. The fraction of this potential benefit which can be realized by improved snow areal extent information depends on factors which cannot be accurately estimated from the available data. This figure,

however, represents an approximate upper limit on foreseeable annual benefits from this source.

#### F.6.5.3.2 Improved Technical Efficiency

In Palisades' normal operating range, an additional foot of effective head results in average increased generation of approximately .9096 KWH/AF.\* A 25% reduction in positive forecast error, if used entirely to increase storage level, would raise the water level at Palisades by about 6.7 feet.\*\* If all of Palisades' annual (1970-74) power discharge of 2,200,000 AF passed through the generators at this increased head, the difference in generation would amount to

$$6.7\text{ft} \times .9096 \text{ KWH/AF/ft} \times 2,200,000 \text{ AF} \times .001 \text{ MWH/KWH} = \\ 13,400 \text{ MWH.}$$

Because of the abundance of runoff at Palisades, however, only a small fraction of this benefit is in fact realizable. Inflow exceeds turbine capacity by such a large margin that spillage is almost continuous between April and September in most years. Forecast errors can therefore be

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\*This figure is derived from the following equation for a least-squares linear regression of KWH/AF against effective head (H) for 30 data points between 1970 and 1974:

$$\text{KWH/AF} = -13.959 + .9096H$$

\*\*The average surface area of Palisades at mean effective head (223 feet) is approximately 10,700 acres (WSP 1934:48). A change in storage of  $288,000 \times .25 = 72,000$  AF therefore corresponds to a change in head of 6.7 feet.



compensated in the course of the runoff season, and errors in April-July forecast can have little impact on postseason storage levels. Benefits from increased head are therefore to be expected primarily during the flood-control season, when an overforecast may result in unnecessary drawdowns for flood reservation space.

In estimating the magnitude of potential benefits from this source we make the following assumptions: (1) benefits are realizable between 1 April and 30 June; (2) power releases during this period average 90,000 AF/wk (see hydrographs); (3) forecasts are subject to improvements of up to 25%; (4) overforecasts occur, on the average, every second year; (5) of the reduction in positive forecast error, 25% results in increased storage for the duration of the period in question.

Under these assumptions, undiscounted annual benefits from improved technical efficiency amount to

$$\begin{aligned} &90,000 \text{ AF/wk} \times 12 \text{ weeks} \times .9096 \text{ KWH/AF/ft} \times 6.7 \text{ feet} \\ &\quad \times .25 \times 1/2 \times .001 \text{ MWH/KWH} = 823 \text{ MWH} \times \$20/\text{MWH} \\ &= \$16,500 \end{aligned}$$

If assumption (5) is relaxed, annual benefits up to \$66,000 may be realized.

#### F.6.5.3.3 Improvements in Economic Efficiency

The available information does not permit accurate estimates of potential benefits from this source.

#### F.6.5.3.4 Flood-control Benefits

Because of limitations in downstream channel capacity, flood-control requirements set significant constraints on Palisades operation. On at least three occasions between 1960 and 1970 (in 1963, 1964, and 1965), flood damage occurred downstream from Palisades as a result of releases from the reservoir. (DMU, p. 305) Most of the flood plain below Palisades is agricultural land: according to one estimate, this limits probable damage, even in years with peak flows much greater than those observed during the 1960's, to the order of \$500,000 or less.\*

However, the available correlations of flood damage to Palisades outflow do not reflect subsequent improvement in the levee system below the dam.\*\* Therefore, though benefits from flood damage reduction at Palisades may be significant, it is not possible to quantify these benefits on the basis of available data.

#### F.6.5.3.5 Irrigation Benefits

Generally speaking, agricultural water-supply in the Palisades irrigation region is sufficient for current requirements in all but the driest years (LIN). It is likely, therefore,

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\*DMU, p. 303, quoting a 1967 estimate by the Army Corps of Engineers.

\*\*Conversation with Richard Lindegrin, August 8, 1975, and DMU, p. 291.

that benefits from this source are relatively small. A rough upper limit may be estimated as follows: assume that forecast errors assume a critical role in agricultural management every fourth year, and that in those years 50% of the absolute reduction in forecast error results in additional economically usable irrigation water. One recent estimate places the value of irrigation supplies in this region at \$5.50-\$11 per acre-foot.\* Since these estimates represent average rather than marginal values, the lower end of this range is used in the calculation which follows.

Under these assumptions expected undiscounted annual benefits from a 25% forecast improvement are

$$288,000 \text{ AF}^{**} \times .25 \times .5 \times 1/4 \times \$5.50/\text{AF} = \$49,500.$$

#### F.6.5.3.6 Miscellaneous Benefits

Palisades is also managed for wildlife protection and recreation. However, the available data do not permit quantitative estimates of benefits to these functions.

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\*DMU, pp. 304, 314, quoting Donald J. Street, Economist, Bureau of Reclamation, Boise. Figures adjusted for inflation from release date of Michigan report.

\*\*This figure represents absolute mean forecast error for the years 1970-74.

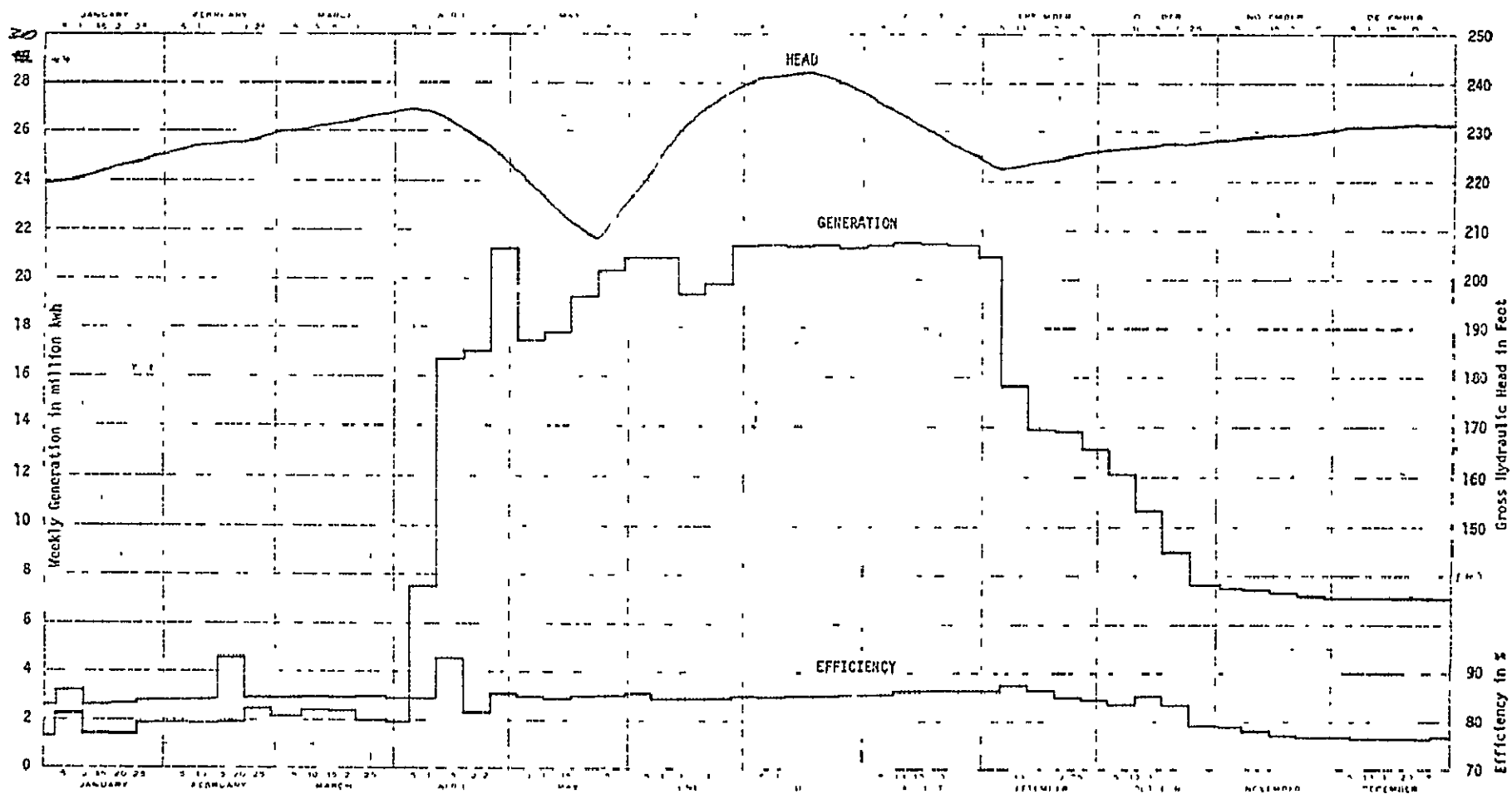


Figure F.6.6 Gross Head, Weekly Generation and Plant Efficiency at Palisades, 1970

Source: U.S. Bureau of Reclamation, Boise, Idaho

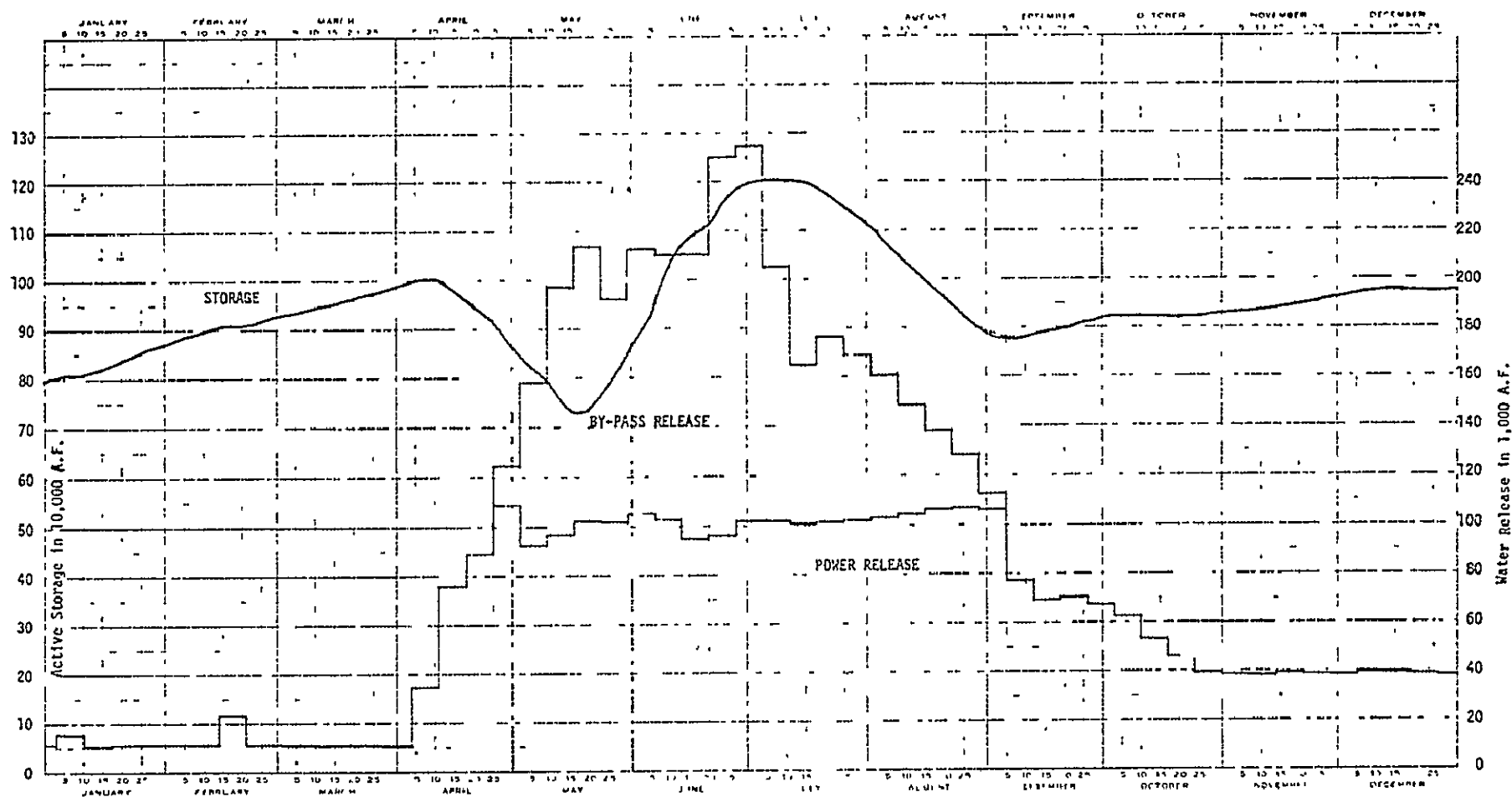


Figure F.6.7 Storage and Weekly Power Releases at Palisades, 1970

Source: U.S. Bureau of Reclamation, Boise, Idaho

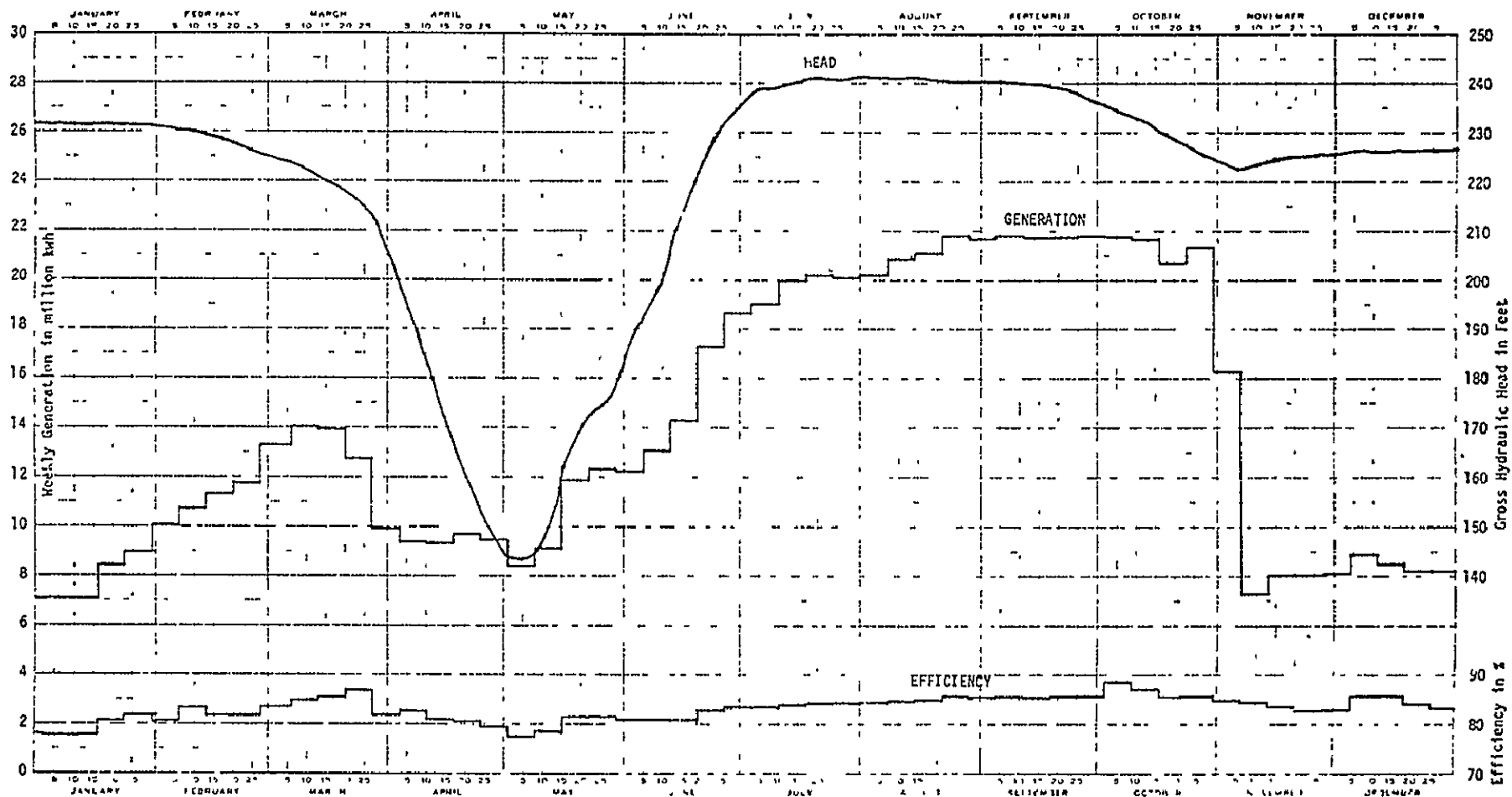


Figure F.6.8 Gross Head, Weekly Generation and Plant Efficiency at Pallsades, 1971

Source: U.S. Bureau of Reclamation, Boise, Idaho

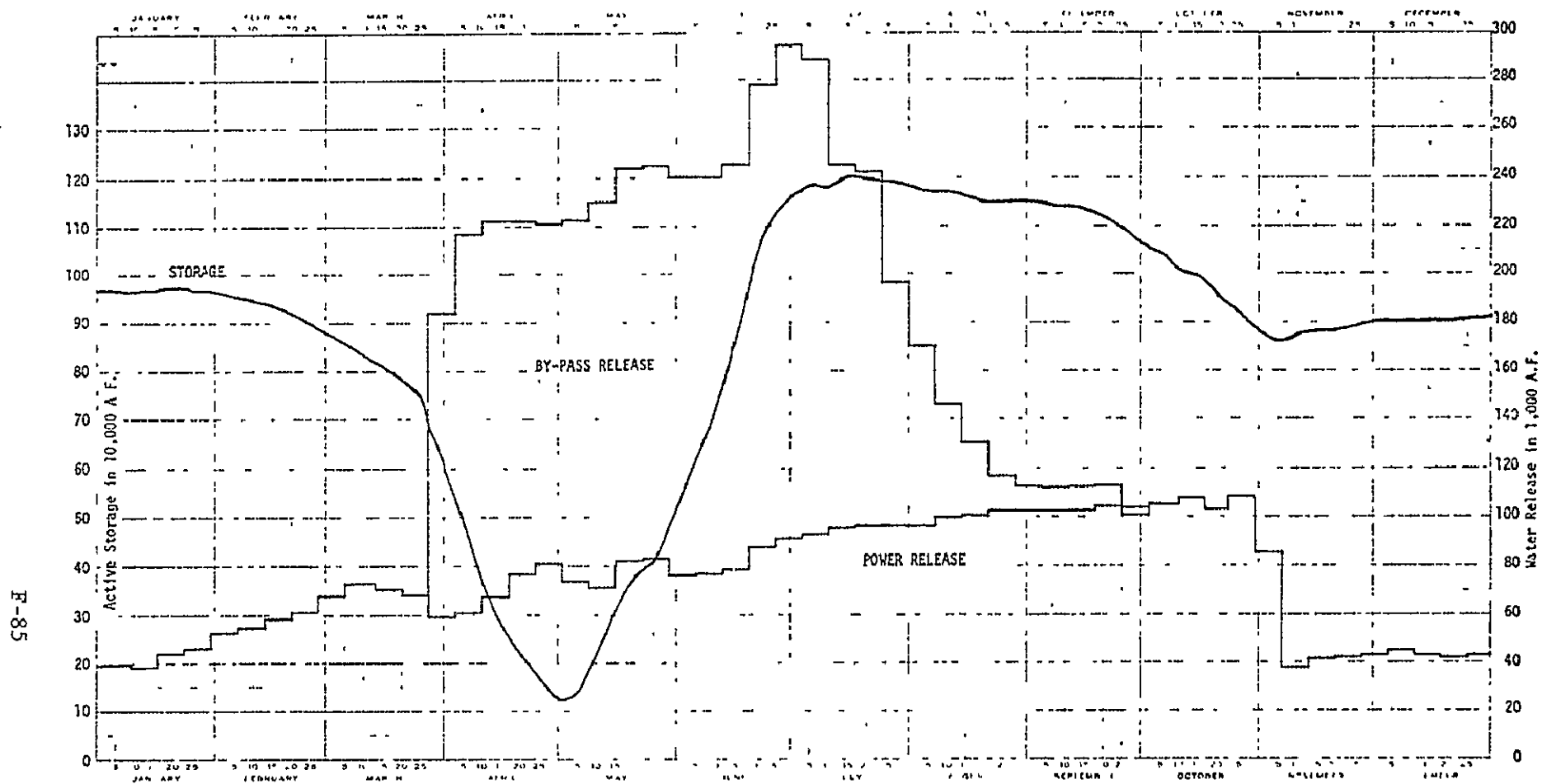


Figure F.6.9 Storage and Weekly Power Releases at Palisades, 1971

Source: U.S. Bureau of Reclamation, Boise, Idaho

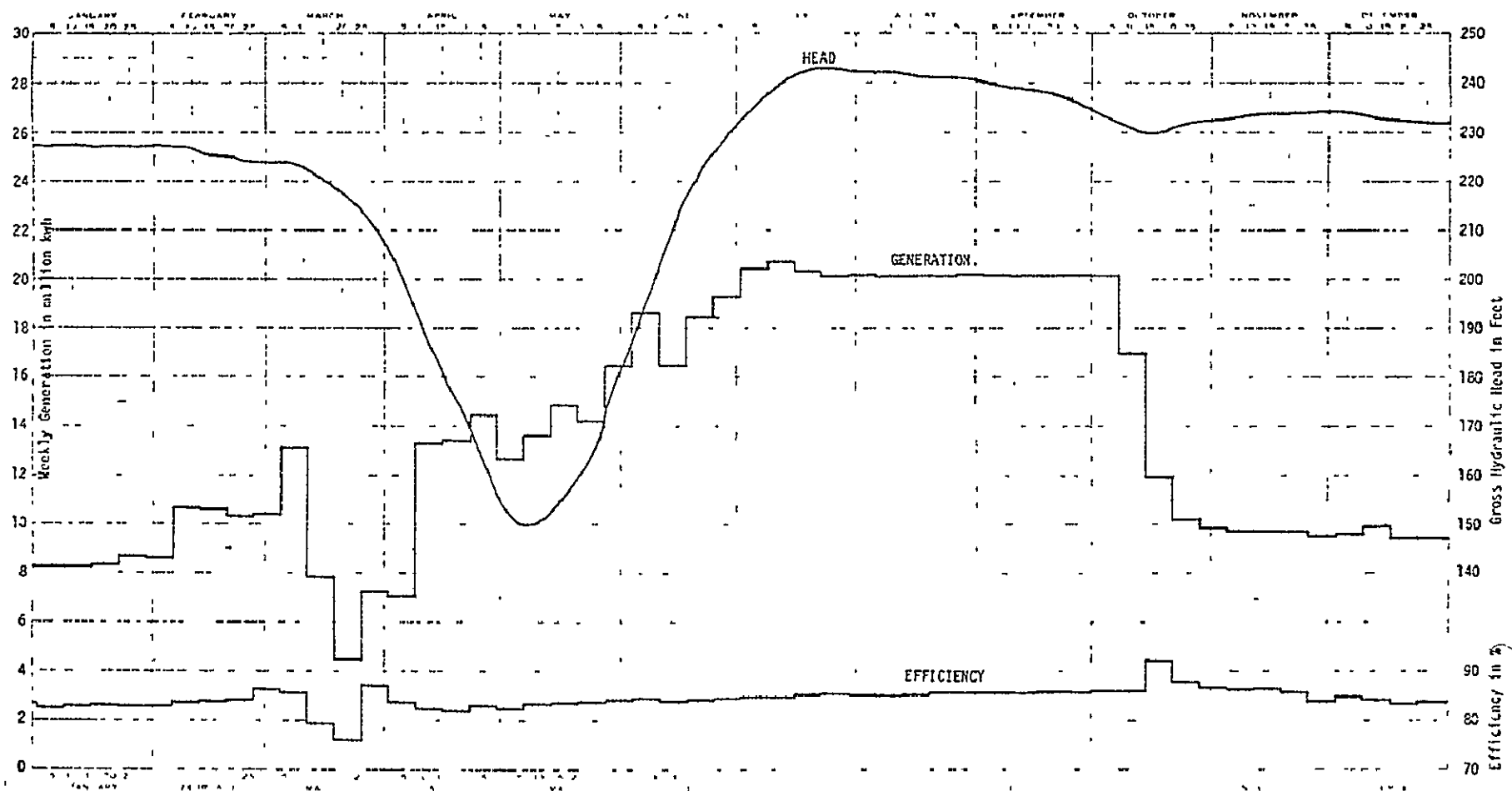


Figure F.6.10 Gross head, Weekly Generation and Plant Efficiency at Palisades, 1972

Source: U.S. Bureau of Reclamation, Boise, Idaho



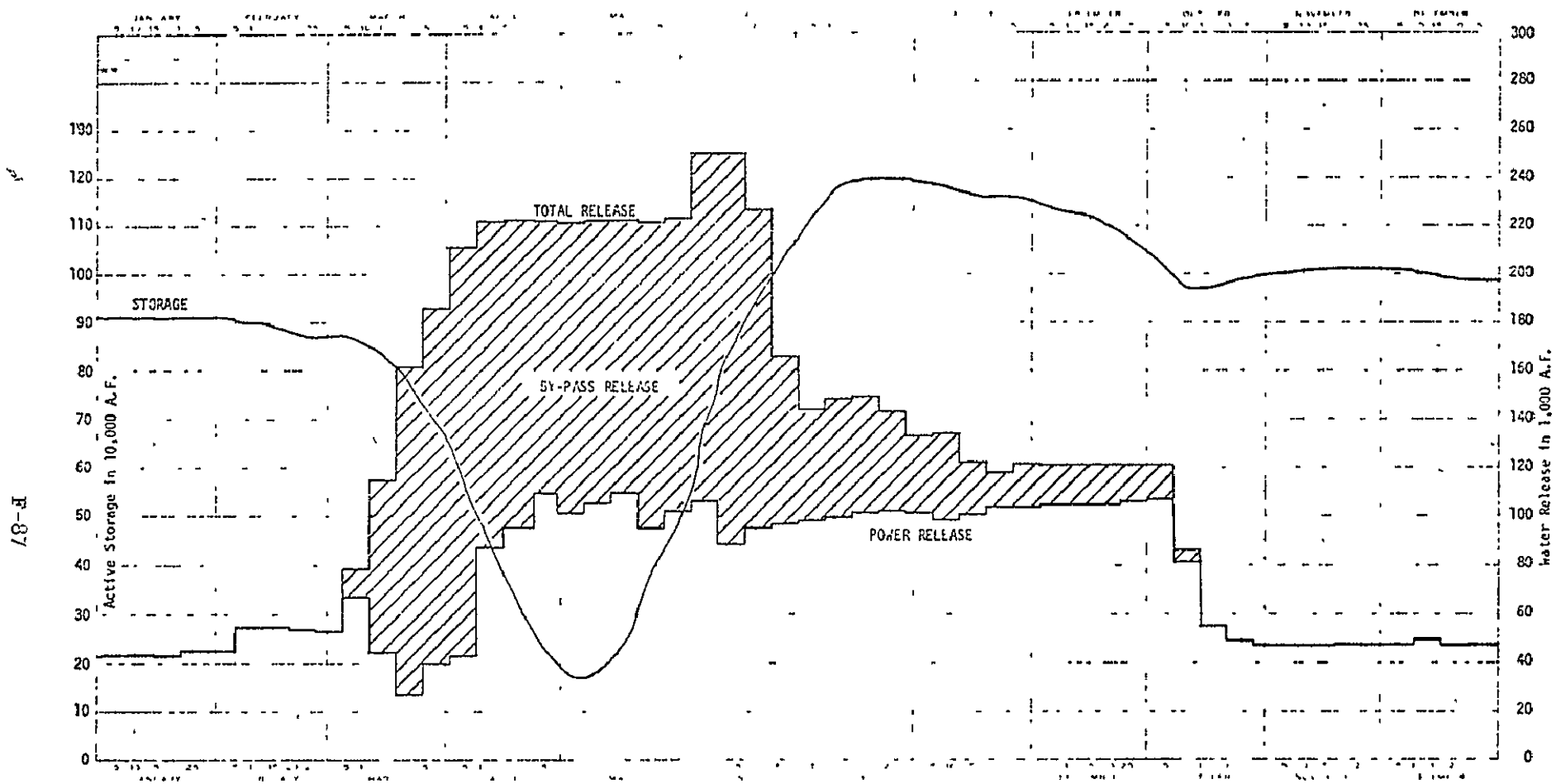


Figure F.6.11 Storage and Weekly Power Releases at Palisades, 1972

Source: U.S. Bureau of Reclamation, Boise, Idaho

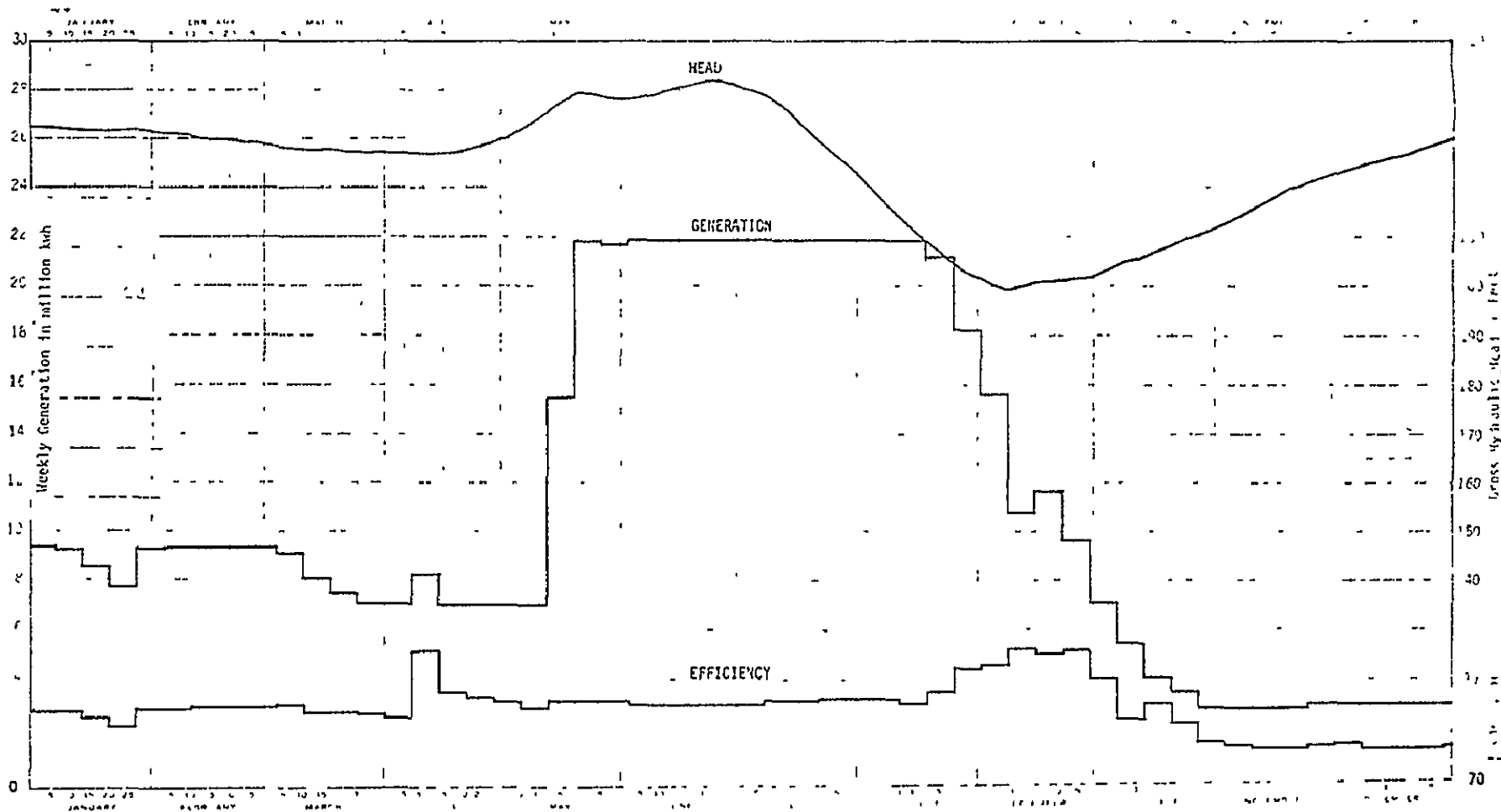


Figure F.6.12 Gross Head, Weekly Generation and Plant Efficiency at Palisades, 1973

Source: U.S. Bureau of Reclamation, Boise, Idaho

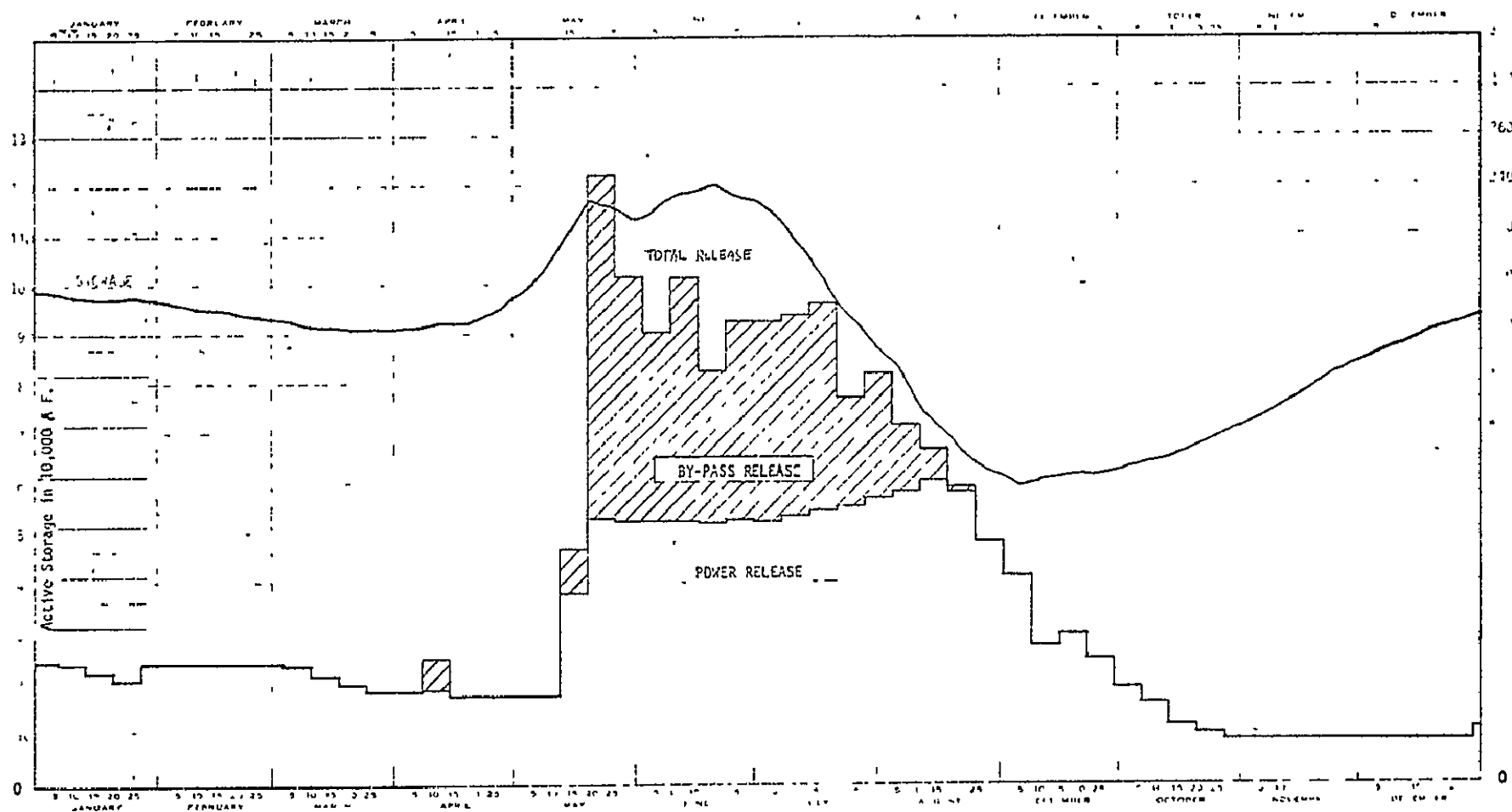


Figure F.6.13 Storage and Weekly Power Releases at Palisades, 1973

Source: U.S. Bureau of Reclamation, Boise, Idaho

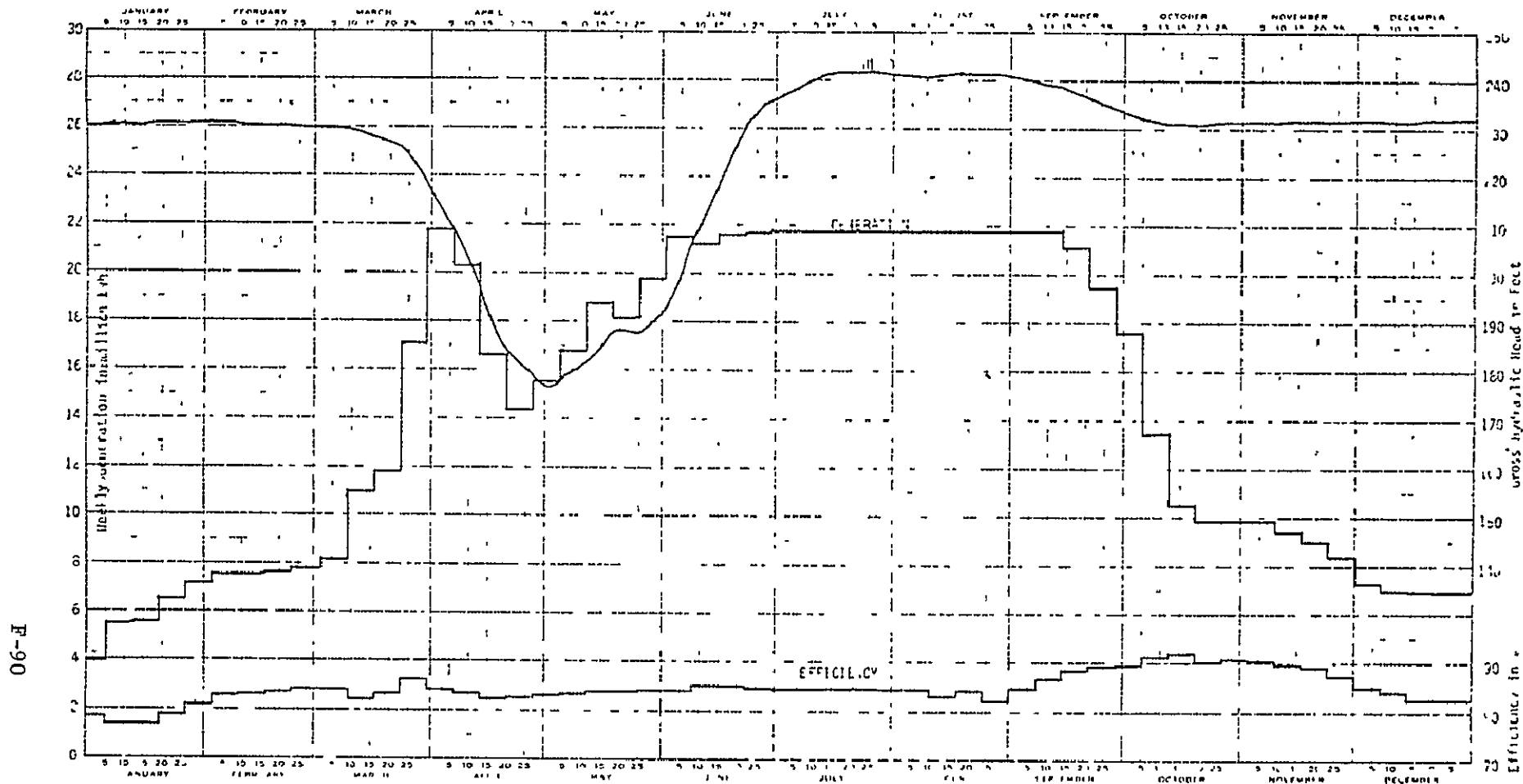


Figure F.6.14 Gross Head, Weekly Generation and Plant Efficiency at Palisades, 1974

Source: U.S. Bureau of Reclamation, Boise, Idaho

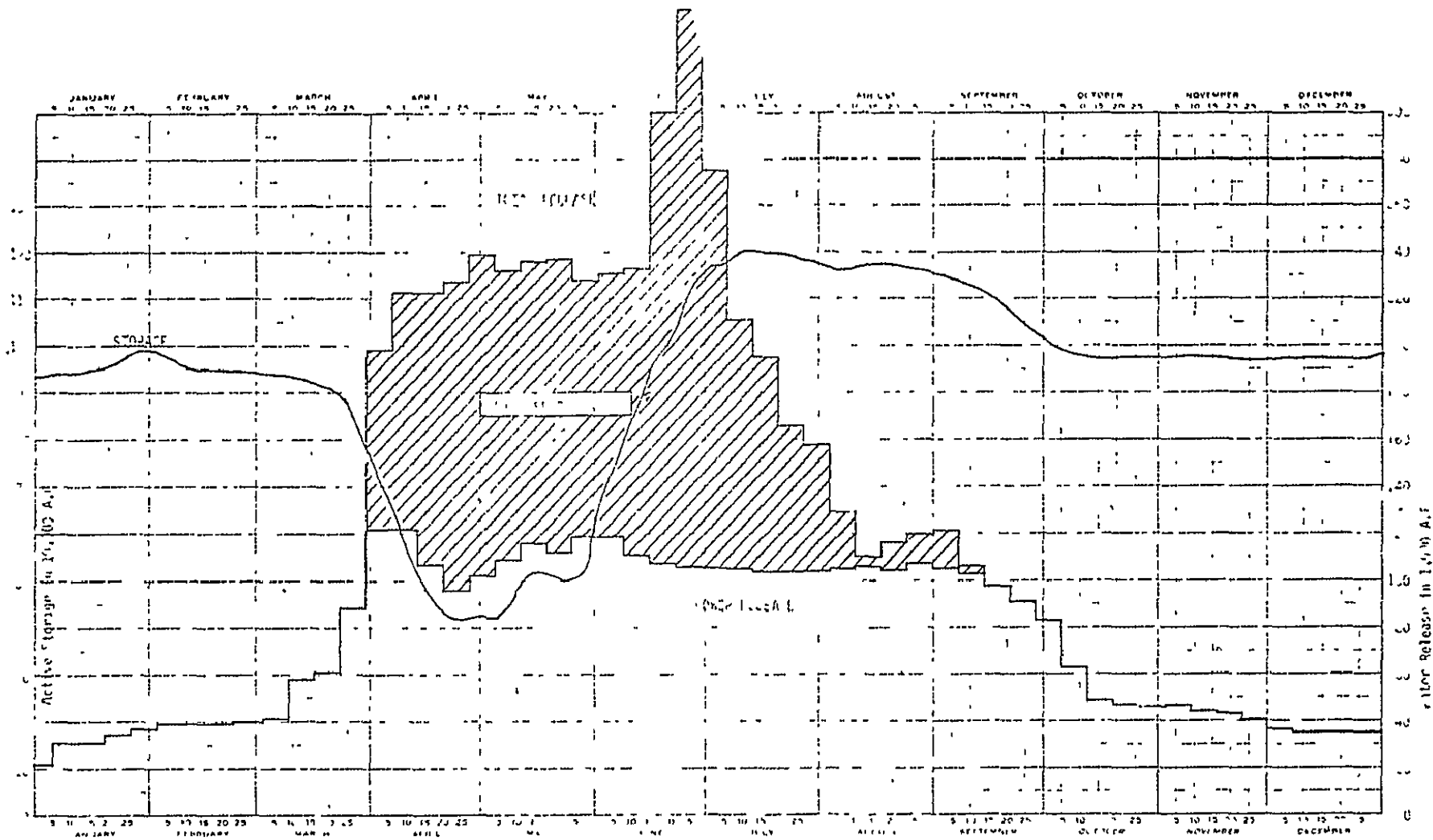


Figure F.6.15 Storage and Weekly Power Releases at Palisades, 1974

Source; U.S. Bureau of Reclamation, Boise, Idaho

#### F.6.6 INTRODUCTION: GRAND COULEE

The highly integrational unit designated as the "Columbia System" is somewhat difficult to dissect into precise component parts. Therefore, upon undertaking to examine the benefits which might accrue from remote sensing at Grand Coulee dam, the largest dam on the Columbia River, one must keep several facts in mind. In particular, regardless of its comparatively large capacities, Coulee (even more pronouncedly than is the case with many other dam systems) does not operate as an isolated system. If benefits are noted to exist for Coulee, as a result of this study, these benefits, in most instances, will affect and/or take into account other reservoirs in the Columbia system as well. Consequently any so-called "benefits" of Grand Coulee will not be realized via immediate management changes; rather, changes will only be viewed and made in coordination with other reservoirs.

This does not preclude the significance of Grand Coulee as an individual base point for a benefits examination or possible remote sensing site but, solely reflects some considerations which could lead to modifications of final benefits estimates at this dam.

Viewed individually, Grand Coulee is quite impressive with its reservoir (for lake) draining an area of 74,700 sq. mi. (SURFACE WATER SUPPLY).

The dam itself is located at an elevation of 1300 ft. on the Columbia River, and is bordered from the ocean air by the higher-lying cascade and Wenatchee Ranges (West) and from Canadian weather by the Rockies. Although all of these affect the climate of the Columbia River somewhat, the Cascades seem to provide the most significant contributions in terms of snow and runoff.

Significantly runoff to GC is 77,630 (1000's a-ft. 1953-67 av.). Much water can presently be stored above GC, 45% av. yrly. streamflow, and drawn to GC as needed (Black Dam). The rest flows to FOR Lake which has a capacity of 9,402,000 acre-ft. (dimensions: 123.44 area, 375 ft. depth, 302 mi. shoreline) (WATER ENCYC, WS OUTLK). This inflow serves a number of purposes-as Grand Coulee is a multi-purpose res. Irrigation, Power RR, FC, & N are treated in such a way as to maximize total benefits.

Concerning the areas to be evaluated in this study, GC presently has the enormous rated cap 2,076,000KW (PURPPAMPHLET) w/average annual generating capacity of 16,330,000 KWH WS PAPER-USGS). This includes 6 pumping units-2 reversible. Under construction is a 3rd P Plant w/a goal of 9.8 mill KW rated cap(PURP) This water is marked as low cost KW, used in indust, etc.

Snow accumulation at Grand Coulee extends from September through March with variations in this time scheme according to elevation. Early in spring (April) snow will reach a maximum on average. However, in the valleys, snow may already have begun to melt in March, while in the mountains it may fall until later periods.

Throughout the year the snow cover may reach great extents. In winter, cover over the 74,700 sq. mi. drainage area approximates 100%. That part of the pack ( 10-20") which falls in the valley is short-lived. It lasts only a month or so. In contrast, principal snowpacks such as the Cascade range may remain through a mid-November to June period; and this year ('75) there was still an estimated 5% residual in July. Quantitatively, in the 5000-8000 ft. crests of the Cascades the pack accumulation is at 10-20 ft. out of 300-500" (with density 25% early winter)--45% March, p. 213). During this season, snow is sur-

vayed for runoff prediction models by the SCS who runs much of the snow data network. Snow water equivalent data is available starting January 1. It is prepared monthly through June and utilized in both individual reservoir manager models (set up for local problems) and system models. SCS forecasts are mainly used by irrigators.

In coordination with one another, some other agencies work on a (SSARR) model where snowline, precipitation, volume, and temperature are major inputs. Subsequently, each agency uses the model for their own purposes, i.e., NWS, Corps (for flood control, and BPA to set up a hydro model for the Columbia System). The latter prepares a 95% confidence level forecast (Watkins).

Generally there has been a need, in the basin, for data besides that collected by SCS. An estimated \$124,971 was spent in the state of Washington to gather snow data to supplement SCS forecasts. A need is particularly expressed for more frequent data however, within the next ten years telemetry should be implemented in the Columbia system.

From surveys it is indicated that runoff from snowmelt is predominant at Grand Coulee. The estimate of melt season runoff, running April-July (March at lower altitudes), attributable to snow is 90%. Based on snow-water equivalent, the SCS forecasted the (Ap-S 1975) flow to streams from mountain snowpack as 71,000 1000's acre-ft. or 103% of the 1953-67 average (with 85,139 1000's acre-ft. occurring the previous year). This places the average at 68,932.04 1000's acre-ft.)

The figures for Grand Coulee are representative of the general importance of snowmelt as runoff in this part of the Columbia basin. Although it may be the



case that remote sensing would not yield benefits at Grand Coulee itself, R. Lindgren (Bureau-expert in this region) feels that there is a good chance for appreciable benefits from remote sensing at the Columbia Basin as a whole.

Personal Reference to be put in Tabular Form:

Accum	75% Oct-March, high Sept-March+
Max.	April
Melt	Low-March; High-April thru July
Amount	Low - 10-20", Winter
Duration	Low - one month; High - December-June

#### F.6.7 HOOVER (See Fig 6.7-1)

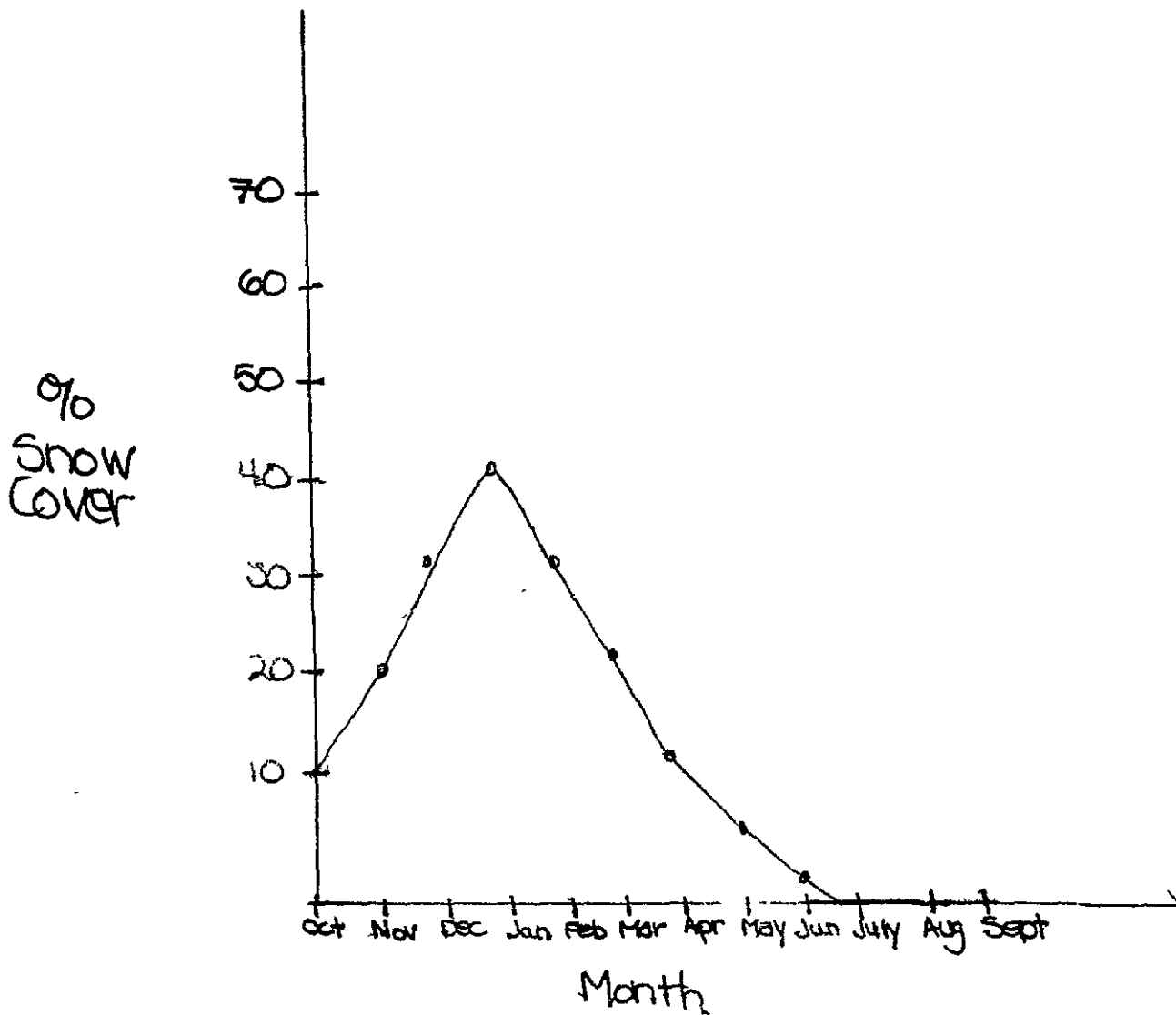
The question of the need for satellite snow monitoring for Hoover Dam (Lake Mead) seems to elicit a negative response. Invariably, runoff at Lake Mead is small in comparison to reservoir capacity. The reservoir capacity/annual inflow ratio is approximately 2. Almost all of the inflow is highly regulated by upstream reservoirs. As a result, there are system-imposed limitations on the variability of flow to Hoover and adequate forewarning of the upstream situation. This points to the likelihood that Hoover has a less pronounced need (if any) for snow data, via satellite, than its upstream associates.

In areas immediately adjacent to Hoover, there is very little snowfall. When snowfall does occur, the high rate of evaporation places a four to five day time limit on the duration of this snow.

Attempts to delineate specific deadlines as to the snowfall -- snowmelt periods and to quantify the amounts of snow will not be 100% accurate. Each of these is highly contingent upon weather patterns. Loosely speaking, snow accumulation

FIG 6.7-1

% Basin Snow Covered at Glen  
Canyon Dam (above Lake Mead)\*



\* here an estimated 65% of runoff is  
due to snowmelt (Letter from EF Sullivan, Bureau  
of Reclamation, Wash. DC).

may commence in October or September. Resultant runoff will start in late March to April to be safe -- and usually by mid-May or June the high pack is gone (but again 80% snowpack may be gone by April-Col. Bur.). Snow can fall (and has fallen) as late as June, extending the runoff period through to August; i.e., this year (1975) the maximum snow came off in July! (Freeney, Mayer: Bureau).

Snow-forecasting at Hoover has a long history (1951 - ?). Presently the reservoir forecasters allot approximately one man day/month for forecasting. Data covers close to 54 stations, including: the Colorado mainstem, parts of Wyoming, the Rio Blancos, the Unitas, and other valley and mountain areas composing 80-90% of the entire basin (Freeney, Mayer).

Additionally, snow water content data is received monthly from two SCS stations. Thus far, this data has been fairly accurate. The only (minor) complaint registered deals with timing; i.e., a delay in receiving data (till the middle of the month). Beyond this, the few foreseeable improvements in the data base would result from data on temperature and soil moisture.

While undergoing present recorrelations, a small forecast error for Hoover was encountered. It is unknown which parameter caused this error. The most likely candidate is "precipitation" (probably rainfall). This error has not been catastrophic; however, as Lake Mead has not had to spill since 1941 (Freeney, Mayer). Thus, upon the conclusion of a consultation with some managers of Hoover Dam (Freeney and Mayer) a suggestion was made that Lake Powell, upstream from Lake Mead, would better indicate the potential for satellite snow data at reservoirs--as Lake Powell still has spill potential\*. But there is a future possibility that these two reservoirs may join forces and eliminate al-

most totally the need for other data among both of these implements.

#### F.6.8 SWIFT

Swift Reservoir is located on the Lewis River between the Coast and Cascade Ranges. There is continual rainfall in the zone surrounding Swift from the fall through the spring. Annual percipitation in this area averages from 120 to 130 inches, with 75% of the percipitation occuring during the period from October through March. In the winter, about 15 to 25 days per month are rainy. Approximately 80 percent of Swift's runoff has been estimated to come from winter, and spring rain and, the only serious management problem--floods--arises from rainfall.

The rainfall at Swift is associated with a phenomenon which would greatly obstruct satellite snow monitoring at the dam. This is the extent of cloud cover. A figure indicative of the great frequency of cloud cover is the statistic given for the number of clear days in the Swift region (N. Pacific Study, p. 637)--4-7 days in winter and 10-15 days in spring.

Needless to say, Swift's managers were somewhat surprised and puzzled as to the fact that their dam was under consideration for remote sensing benefits. Even excepting cloud, cover, they stated that the only usable snowpack (or period

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\*In reference to this statement; further investigation showed that Lake Powell is currently operating according to its requirements rather than its inflow, since this reservoir will not be full until approximately four years from now.

when snow melts) is in January and February. This includes lower areas ( 80% of Swift's drainage areas is under 4000 ft.), where the 10" snowfall usually lasts less than two weeks, and some higher areas. In the latter group are the Cascades, from which the Lewis River flows westward and, in particular, areas where water is stored in glaciers, i.e., Mt. St. Helens (9,677) and Western Mountain Adams(12,307).

In summary, Swift does not seem to be a likely candidate for benefits from monitoring snowpack. Firstly, most of its runoff is due to rain; and secondly, the frequency of cloud cover is too great.

#### F.6.9 BLUE MESA

##### INTRODUCTION

Blue Mesa on the Gunnison River has notably small absolute capacities than the other dams studied. Its storage capacity is in the realm of 1 degree of magnitude smaller, excepting Swift Reservoir (which is 200,000 less). Installed capacity is only 60,000 and average annual generations is 280,000. This however does not decrease the possibilities of benefits at this reservoir; and it may in fact, do the contrary.

Blue Mesa is a small multipurpose dam in a high snowfall region which must be acutely aware of the snow and runoff conditions in its proximity. In this regard, one of the dams foremost functions is flood control for which BM must be gaged towards short term response, i.e., daily. Flood control is important in 2 major senses. Most obviously, it is essential for the sake of protection of all properties on and near the River. Blue Mesa is the only dam with this capability.

Flood control is also extremely important on the Colorado as it affects hydropower generation. The hydropower situation at BM is tight for although Colorado has much storage, it has little hydropower generation and must presently purchase from Columbia System. The value of water for power is calculated at 20:1 (loss of energy from spilling/not filling). This means it is 20x more costly to spill by 1 extra unit than to not fill. Hence, considerable precautions in terms of conservative flood control margins and daily hydropower level are taken at BM. Necessarily, the degree of precautions taken is highly associated with her ability to predict runoff.

Runoff at Blue Mesa is 80% due to snowmelt. This potential threat/aid extends from October through the early summer months. As is expected of a dam situated at or near high elevations, BM still has 30% snow cover in April & 20% May. (making monitoring still import)

The management of Blue Mesa Reservoir is greatly affected by its reservoir forecast and by the accuracy of each parametric input to this forecast especially snow. A strict limit is set on the allowable forecast error by two locationally linked factors. Firstly, Blue Mesa location, upstream, in mountainous terrain makes it susceptible to any sudden and/or predicated changes of weather. Both high rainfall and snowmelt are immediately intercepted by this reservoir prior to any man-made regulation or other diversions. Hence, Blue Mesa must be able to predict accurately those climatologica conditions which are predictable, such as amount of snowpack; and, also, it must respond quickly to any of several unpredictable events that may occur. A further burden of responsibility placed on BM is the need to account for (all other downstream reservoirs on the Colorado River--whether it be respecting the constraints

placed on BM by downstream requisites for additional water, i.e., irrigation or, realizing the obligation to be moderate in her releases so as not to create a flood threat.

A very crucial element in the BM forecasting equator is snowfall. Presumably, this is the parameter which most (?) indicative of runoff. (Precipitation is not as good an indicator of runoff as snow is--Don Barnett). Major areas contributing snow to the general drainage basin are (1) the Rocky Mountains-ets of Blue Mesa, (2) Main Colorado, (3) Green Wind River and (4) San Juan. Accumulation begins in October, with snow existing above BM in January at least 90% of the time, and continues to April 1, whereupon melt season starts. Approximately 2/3 total runoff occurs from April-July. This runoff is counted as snowmelt (Barnett). For whereas the Lake Powell area is 80% snowfree come April 1, Blue Mesa still has a high significant percentage of snowpack in its uppper elevations.

Forecasts for dowsstream res. are made once a month January 1-June. Measurements are taken physically (using a manned labor forre) and they cover up to 50 snow courses; i.e., above Lee's Ferry, above Flaming George, above Blue Mesa, . . . and Lake Powell make use of the same forecast sheet and set up similar forecast equations (w/5 year revisions). Forecasting is done via multiple regression variables set up to correlate snow water content vs runoff.

With the upcoming implementation of telemetry forecasts will soon be more frequent. It is a possibility that they may even be available daily; although one time per week is often enough. (Barnett) Beyond increased frequency the most useful aspect of telemetry is that it will aid monitoring after big storms.

In reference to forecasts, a Blue Mesa manager asserted that "the main source of error is spring precipitation" since measuring stations are changed and the update cycle is only 1/month. Both consistency of measurements, and greater frequency of forecasts will be considered improvements at Blue Mesa. There is also potential for improving timeliness at this reservoir as even "a 1 month advance (on data receipt) will have a big effect on data." It is therefore reasonable to be optimistic as to the future uses of satellite photography at Blue Mesa--a "small" upstream reservoir.



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**APPENDIX G**  
**AREA MENSURATION ACCURACY**

## APPENDIX G

### Area Mensuration Accuracy

#### G.1 RELATIVE EFFECT OF IFOV AND S/N

Analysis of the effects of instantaneous field of view (IFOV) and signal to noise ratio (S/N) on TOSS system performance has been undertaken. Necessary and sufficient relationships to perform requisite system trades have been derived and are presented herein. The analysis can be characterized as rigorous but incomplete: what has been done is sound, but certain simplifying and restrictive assumptions have been made either due to lack of information or to added complexity deemed unwarranted for the TOSS study. These assumptions and their implications are of course explicitly described in the following.

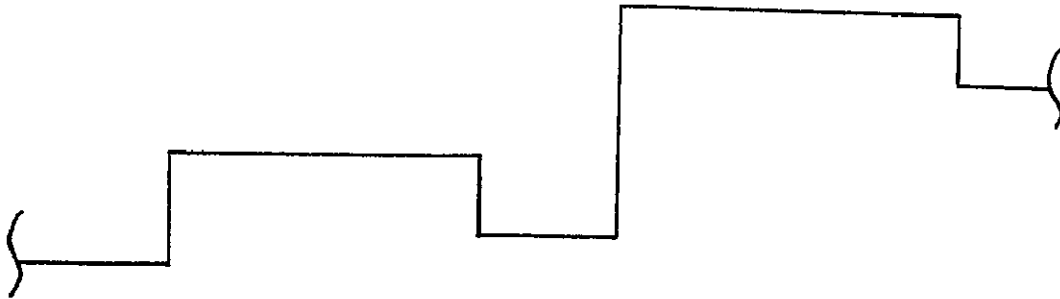
Relationships between IFOV and S/N and both area measurement and radiance measurement accuracies are given. Numerical data are presented where available.

##### G.1.1 MODEL:

###### G.1.1.1 Input:

The input to the sensor is in general a stochastic variable  $R(x,y)$  where  $R$  = radiance (watts/ster.  $\text{cm}^2$ ),  $(x,y)$  = position coordinate on the earth's surface. However, for the four TOSS missions, the objective is to find regions of homogeneous radiance and to determine the areas of those regions, thus yielding acreage estimates of crop type, snow extent, usable rangeland. Therefore,

the input may be modelled in the TOSS context as a function completely characterized by finite constant levels, and loci of discontinuity between different valued levels; e.g. any slice through  $R(x, y)$  (perpendicular to the  $(x, y)$  Plane) would look something like:



This input model is adopted as "Assumption 1"

#### G.1.1.2 System:

Assumption 2: The system is linear in radiance, the linear operation constituting a gain and a scanning of  $R(x, y)$  with some aperture (detector). If we choose the coordinate system  $(x, y)$  such that " $x$ " coincides with the scan direction, the detector now yields some function of one dimension,  $S(x)$ , which constitutes the image data. The one dimensional  $S(x)$  may be dimensional distribution  $R(x, y)$ . The actual mathematics involved is somewhat messy and will not be necessary for our purpose.

Assumption 3: The system introduces additive, white, zero mean, gaussian noise. The actual observation is thus:

$$(1) \quad I(x) = S(x) + u(x)$$

where  $u(x)$  is a sample value of an "Assumption 3" process and is completely characterized by the noise standard deviation, " $\sigma_N$ ".

## G. 1.2 DERIVATION

### G.1.2.1 Fundamental Equations

It is desired to estimate the radiance level and area of some field, snow-patch, grassland, etc., when it is apriori known that the radiance level is constant and is discontinuously bounded. Specifically we desire to know the estimation errors in radiance and area, as a function of IFOV and S/N. To accomplish that objective requires first obtaining relationships between the performance parameters and boundary and radiance estimation.

For the given system model (Assumptions 2,3) the errors will be unbiased and gaussian and thus completely described by their variances:

$$\sigma_{x_0}^2 = \text{variance in estimating location of discontinuity in radiance}$$
$$\sigma_F^2 = \text{variance in estimating constant radiance level.}$$

Assumption 4: The cross section of the IFOV is square.

Assumption 5: The "field" boundary is approximately a straight line over distances the size of the IFOV and is approximately perpendicular or parallel to the scan direction.

Assumption 6: The boundary is located near the center of a region long compared to the IFOV.

Let: the IFOV be " $w$ " (meters)

Now if we consider one slice,  $S(x) + u(x)$ , through  $R(x, y)$ , there exists



a lower bound on the variance in boundary location estimation given by:

$$(2) \quad \sigma_{\hat{x}_0}^2 \geq \frac{4\sigma_n^2 w^2}{(\Delta R)^2}$$

where:  $\sigma_{\hat{x}_0}^2$  = boundary location estimation variance  
 $\sigma_n^2$  = noise variance  
 $w$  = IFOV  
 $\Delta R$  = radiance difference across boundary

Assumption 7: The field is large compared to  $w$ . Then there exists a lower bound on the variance in radiance estimation given by:

$$(3) \quad \sigma_{\hat{r}}^2 \geq \frac{\sigma_n^2 w}{x_1}$$

where:  $\sigma_{\hat{r}}^2$  = radiance level estimation variance  
 $\sigma_n^2$  = noise variance  
 $w$  = IFOV  
 $x_1$  = field length

If relative performance, TM vs. MSS is desired, (2) and (3) yield simply:

$$(4) \quad \frac{\sigma_{\hat{x}_0}^2(MSS)}{\sigma_{\hat{x}_0}^2(TM)} = \frac{(\sigma_n w)^2_{MSS}}{(\sigma_n w)^2_{TM}}$$

$$(5) \quad \frac{\sigma_{\hat{r}}^2(MSS)}{\sigma_{\hat{r}}^2(TM)} = \frac{(\sigma_n^2 w)_{MSS}}{(\sigma_n^2 w)_{TM}}$$

#### G.1.2.2 Noise Specification:

Two different means to specify noise seem to be in use by NASA. The TM (and EOS) point design specification state a minimum radiance,  $R_{min}$  (watts/ster  $cm^2$ ) and require that the noise equivalent radiance be a certain fraction of that value. The Purdue TM specification, on the other hand, specifies noise equivalent reflectance and gives reflectance corresponding to full scale per band. If we neglect atmospheric, the two may be made consistent by specifying  $\sigma_n$  as a percentage of full scale, which procedure will be followed henceforth.

#### G.1.2.3 Criticism of Assumptions

1. Input is not actually constant over fields of interest. A better model would be the one adopted plus some stochastic variable  $r(x,y)$ . This was not done for two reasons: it significantly complicates the analysis, and no data to describe  $r(x,y)$  are available. The assumed model is adequate for the TOSS perturbation analysis.

2. This is a correct representation. Some detectors are non-linear, but specification of adequate linearity over the operating range is included in the instrument designs.

3. For solid state detectors (to be used throughout the TM), the noise is additive and gaussian. However, it is unlikely to be white. No data on the actual noise power spectra for the instruments is available, so the white assumption was adopted. "Colored" noise can be included in the calculations if data becomes available. For photomultipliers (PMT), performance is photon limited and the noise amplitude is consequently signal dependent and non-gaussian. Thus, in calculations concerning MSS performance in the first three bands, best and worst case values are given. That the detector noise statistics are not gaussian is ignored.

4. If the detector were perfectly imaged and all electronics were not band unlimited this would be the case. The IFOV concept is a simplistic representation of the total system impulse response. No data on the actual shape of the impulse response is available but would be utilized if it were.

5. If the field boundary is a straight line over an IFOV distance, an expression for boundary estimation is available. Analogous expressions can be derived for randomly shaped boundaries over the IFOV distance, but the significant complications introduced are unwarranted in this context. The part of the assumption that required the boundary to be orthogonal to one of the scan axes is non-essential. It is adopted because it yields a particularly simple algebraic expression for the boundary detection variance (eqn. 2). When the boundary is at an arbitrary angle to the scan direction, (2) would yield a slightly higher variance. This uncertainty is small compared to the uncertainty introduced by lack of knowledge of the true shapes of the impulse response and noise power spectrum. Equation (2) is always a lower bound, but should be reevaluated for angle dependency when instrument data available.

6. "Long compared to the IFOV" means, qualitatively, that there are enough samples to make the decision that two constant and estimable levels on either side of a boundary exist. The necessary length depends on how noisy the record is. An optimal estimate could require at least a small number of IFOV's on either side.

7. The comments under 6. are repeated here. In both cases, as the size of the record approaches the IFOV the variances begin to increase rapidly with respect to the expressions in equations (2) and (3). In other words, (2) and (3) are valid only above some threshold size linearly related to the IFOV.

In examining the assumptions, we find that: 1. and 2. represent rather universally accepted modelling concepts, 3. and 4. are adopted because the necessary "real" data on the requisite instrument performance descriptors is not available, 5., 6. and 7. are non-essential and are adopted only because they

simplify the analytic task and yield simple algebraic expressions amenable to intuitive contemplation. The error introduced into the absolute values of the variances computed by our results due to 3. and 4. is large compared to that introduced by the non-essential 5., 6. and 7., otherwise the latter three would have not been used. When accurate data for the instrument performance descriptors becomes available, assumptions 3. thru 7. should be eliminated and correct absolute variances computed.

However, for the purpose of TOSS, we are concerned mainly with differences in performance of candidate instruments as a function of differences in their performance descriptors: impulse response (IFOV), and noise statistics (S/N). The MSS and TM are similar devices, that is they may be identically modelled. If the analysis results are consistently applied, the computation of performance differences will be accurate, even though the computation of absolute performance of either may be biased due to the assumptions made. That is what was meant in the introduction when it was stated that the analysis was rigorous but incomplete.

#### G.1.2.4 Generalization to Two Dimensions

The relationships given so far are valid only for slices through  $R(x, y)$ . The two dimensional results are required.

Let the area "A" of a constant radiance patch be defined by some function:

$$(6) \quad A = f(x, y)$$

Then the variance in estimating "A" is given by:

$$(7) \quad \sigma_A^2 = \left(\frac{\partial f}{\partial x}\right)^2 \sigma_x^2 + \left(\frac{\partial f}{\partial y}\right)^2 \sigma_y^2$$

where the  $\sigma_x^2, \sigma_y^2$  are computable from (2).

For radiance estimation, equation (3) becomes

$$(8) \quad \sigma_{\hat{r}}^2 = \frac{\sigma_n^2 w^2}{A}$$

#### G.1.2.5 Particular Results for Certain Mensuration Schemes

a) Rectangular fields - Since square ( $w \times w$ ) IFOV's have been assumed, in equation (7) we can put

$$(9) \quad \sigma_x^2 = \sigma_y^2 = 2 \sigma_{\hat{x}_0}^2 \quad \text{where } \sigma_{\hat{x}_0}^2 \text{ is obtained from (2)}$$

For rectilinear fields on constant backgrounds. Thus, for a rectangular  $L \times W$  field, the variance in area mensuration is given by:

$$(10) \quad \sigma_{A_{rect}}^2 = (L^2 + W^2) 2 \sigma_{\hat{x}_0}^2$$

This variance could be achieved by making only two orthogonal line scans of the field. (It, of course, makes use of the a priori knowledge that the field is rectangular). Notice that for this simple algorithm, the relative performance of TM and MSS is given simply by:

$$(11) \quad \frac{\sigma_{A_{rect}}^2(MSS)}{\sigma_{A_{rect}}^2(TM)} = \frac{\sigma_{\hat{x}_0}^2(MSS)}{\sigma_{\hat{x}_0}^2(TM)} = \frac{(\sigma_n w)^2_{MSS}}{(\sigma_n w)^2_{TM}}$$

and is independent of the actual field dimensions. Recall that equation (11)

is valid only for fields larger than a threshold size linearly related to

"w". There will consequently be a region between the MSS threshold and smaller TM threshold where the mensuration variance ratio is very much greater than that shown in (11).

Now consider a more complicated algorithm which makes as many edge estimates as possible and then averages them. In this case:

$$(12) \quad \sigma_x^2 = \frac{w}{L} 2 \sigma_{\hat{x}_0}^2$$

$$\sigma_y^2 = \frac{w}{W} 2 \sigma_{\hat{x}_0}^2$$

From (10):

$$(13) \quad \sigma_{A_{rect}}^2 = 2(W+L)w \sigma_{\hat{x}_0}^2$$

The variance is reduced at the expense of additional calculation. For this algorithm:

$$(14) \quad \frac{\sigma_{A_{rest}}^2 (MSS)}{\sigma_{A_{rest}}^2 (TM)} = \frac{(\sigma_n^2 w^3)_{MSS}}{(\sigma_n^2 w^3)_{TM}}$$

b) Arbitrary Field Shape, Area Function not a priori Known

If the area function were a priori known, we could proceed as in section

(a). However, if the shape is undetermined, one is limited to performing the mensuration on a line by line basis. Each line would have the variance in length of  $2\sigma_{\hat{\lambda}_0}^2$ . The total area is: where:  $\hat{\lambda}_i$  is the estimated line length

$$(15) \quad w \sum_{i=1}^N \hat{\lambda}_i \approx A \quad N = \text{number of scan lines through the area}$$

Since the sum (15) is required to find the area, the variance would be large, given by:

$$(16) \quad \sigma_A^2 \approx 2N\sigma_{\hat{\lambda}_0}^2$$

for this algorithm.

### G.1.3 CALCULATIONS

Noise data is tabulated in Table G-1 for the current TM baseline (Purdue) and for the GE EOS baseline. Best available MSS data is included. The MSS IFOV is taken as 80 meters. TM IFOV is taken at 30 meters (best case) and 50 meters (worst case).

The ratio:  $\frac{(\sigma_n w)_{MSS}^2}{(\sigma_n w)_{TM}^2}$  (= relative boundary estimation variance) is computed for each band, as is its square root (relative boundary estimation standard deviation - the standard deviation is of course in meters and relates intuitively to "error"). Results are given in Table G-2.

As shown above, this ratio gives relative performance for a most simple area mensuration algorithm (rectangular field). A better algorithm was shown to vary as  $w^3$  rather than  $w^2$ , and results for this case are shown as well (for possible use in extractive processor design tradeoffs). Note that the edge detection algorithms need only operate in a single band. Due to the inverse dependence on  $\Delta R$  (see equation 2), it is only necessary to pick the band with the greatest  $\Delta R$  for each particular area to be measured.

TABLE G-1 NOISE STANDARD DEVIATION PER BAND

Noise standard deviation (in percent of full scale) per band.

Band	MSS	TM	GE
	Best Current Data	Purdue (8 bits)	EOS (8 bits)
1	1.39 - 6.15	2.5	.52
2	2.75 - 8.28	.86	51
3	4.22 - 13.2	.94	56
4	1.39	.67	.58
5		.67	3.17
6		1.0	4.63
7		.17	1.31

NOTE: Quantization noise is included

TABLE G-2 RELATIVE PERFORMANCE

Relative boundary and/or area estimation performance above MSS threshold.

Band	$\frac{(\sigma_n \omega)^2_{MSS}}{(\sigma_n \omega)^2_{TM}}$	$\frac{(\sigma_n \omega)_{MSS}}{(\sigma_n \omega)_{TM}}$	$\frac{(\sigma_n^2 \omega^3)_{MSS}}{(\sigma_n^2 \omega^3)_{TM}}$	$\frac{(\sigma_n^2 \omega^3)^{1/2}_{MSS}}{(\sigma_n^2 \omega^3)^{1/2}_{TM}}$
1	16.2	4.02	43.2	6.57
2	292.	17.1	780.	27.9
3	610.	24.7	1628.	40.3
4	30.6	5.53	81.7	9.04
5				
6				
7				

NOTE: (1)  $\omega_{TM} = 30$ . meter(2)  $\sigma_n$  (MSS) set at average  $\frac{\sigma_n^{(max)} + \sigma_n^{(min)}}{2}$  in bands 1-3(3)  $\sigma_n$  (TM) from Purdue Data

1	5.82	2.41	9.32	3.05
2	105.	10.3	168.	13.0
3	219.	14.8	351.	18.7
4	11.	3.32	17.6	4.20
5				
6				
7				

NOTE: (1)  $\omega_{TM} = 50$ . meter

(2) Same as preceding (2)

(3) Same as preceding (3)



## G.2 ABSOLUTE ERROR BOUND CALCULATIONS

It was pointed out in Section G.1 that, because of the assumptions adopted, the results are accurate only for relative comparison of system performance. No stipulation of the accuracy of absolute values was made because it was felt that Assumptions 2 and 3 would not be valid (or necessary) when real data becomes available.

Nevertheless, if a hypothetical system which met all seven assumptions did indeed exist, correct absolute performance bounds would clearly obtain.

The calculations were done because they were easy to do.

The data is documented because it contributes to intuitive insight.

To quote the results presented herein without simultaneously quoting the seven explicit assumptions is to give misinformation.

### G.2.1 PERCENT ERROR IN INDIVIDUAL RECTANGULAR FIELDS

Consider the case of a rectangular field which is measured by an algorithm which makes a single "scan" in each of the length and width directions.

Recall, respectively, equations (10) and (2).

$$(10) \quad \sigma_{A_{rect}}^2 = 2(L^2 + W^2) \sigma_{\hat{x}_i}^2$$

$$(2) \quad \sigma_{\hat{x}_i}^2 \geq 4 \frac{\sigma_n^2 w^2}{(\Delta R)^2}$$

where: L, W are the dimensions of the rectangle  
 $\sigma_n^2$  = noise variance  
 $w$  = IFOV  
 $\Delta R$  = radiance (reflectance) difference between field and surrounding fields

Assume that an optimal boundary detection algorithm is implemented so that equality obtains in (2)

Let:

$$\frac{\sigma_n}{\Delta R} = \rho \quad W = \alpha L \quad \alpha \geq 1 \text{ is aspect ratio}$$

Then:

$$(3) \quad \sigma_{A_{rect}}^2 = 8(1+\alpha^2)L^2\rho^2W^2$$

$$(4) \quad \frac{\sigma_{A_{rect}}^2}{A^2} = 8 \frac{1+\alpha^2}{\alpha^2} \frac{1}{L^2} \rho^2 W^2$$

$$(5) \quad \frac{\sigma_{A_{rect}}}{A} = 2\sqrt{2} \left(1 + \frac{1}{\alpha^2}\right)^{\frac{1}{2}} \rho \frac{W}{L}$$

Data for our assumed MSS and TM are given in Table G-3. Values for  $\Delta R$  of 5., 10., and 50. percent of full scale per band are used. The maximum and minimum field sizes of interest are taken at 25. and 250. acres. Noise values used are as defined in the reference.

The table gives values for square fields. For rectangular fields, multiply by  $\frac{(1+\frac{1}{\alpha^2})^{\frac{1}{2}}}{\sqrt{2}}$

Note that for the 25. acre field, the MSS is in a region of violation of Assumption 6, therefore, the errors will be worse than shown.

#### G.2.2 PERCENT ERROR IN TOTAL ACREAGE (assuming all fields rectangular)

Define the total acreage:

$$(6) \quad A_T = \sum A_i = \sum \alpha_i L_i^2$$

Then:

$$(7) \quad \sigma_{A_T}^2 = \sum \sigma_{A_i}^2$$

Thus:

$$(8) \quad \frac{\sigma_{A_T}^2}{A_T^2} = \frac{8W^2 \sum (1+\alpha_i^2) L_i^2 \rho_i^2}{[\sum \alpha_i L_i^2]^2}$$

Choose worst case values for " $\alpha$ " and " $\rho$ " and assume they obtain in all cases:

$$\alpha_i = \alpha_m \quad \text{for all } i$$

$$\rho_i = \rho_m$$

Now:

$$(9) \quad \frac{\sigma_{A_T}^2}{A_T^2} \leq \frac{8w^2(1+\alpha_m^2)\rho_m^2}{\alpha_m^2} \frac{1}{[\sum L_i^2]}$$

$$(10) \quad \frac{\sigma_{A_T}}{A_T} \leq 2\sqrt{2} \left(1 + \frac{1}{\alpha_m^2}\right)^{\frac{1}{2}} \rho_m \frac{w}{[\sum L_i^2]^{\frac{1}{2}}}$$

But: since  $\alpha_i \geq 1$ ,  $\alpha_m = 1$

since  $\rho \geq \frac{\sigma_m}{\Delta R}$ , take  $\rho_m = 1$

Yielding

$$(11) \quad \frac{\sigma_{A_T}}{A_T} \leq 4 \frac{w}{\sqrt{A_T}}$$

which is amusing.

NOTE: 1) Square fields are worst case.

2) For a given percent error upper bound, both MSS and TM would have to process the same number of image data points (pixels), consequently the data rate/volume trades depends only on the number of bits/pixel.

3) For a given percent error upper bound, MSS would have to cover an area  $A_T(mss) = \frac{64}{9} A_T(tm)$ . It would be more difficult to find an  $A_T$  composed of individual fields which do not violate Assumptions 6. and 7. for the MSS than for the TM.

TABLE G-3 PERCENTAGE MENSURATION ERROR

$$\frac{\sigma_A}{A}$$
 (percent) for 25. acre field

Band		$\Delta R = 5.$	$\Delta R = 10.$	$\Delta R = 50.$
1	MSS	77	38.	7.
	TM	19.	9.	1.7
2	MSS	112.	56.	11.
	TM	6.5	3.3	.64
3	MSS	177.	88.	18.
	TM	7.2	3.6	.73
4	MSS	28.	14.	2.8
	TM	5.1	2.5	.51

$$\frac{\sigma_A}{A}$$
 (percent) for 250. acre field

Band		$\Delta R = 5.$	$\Delta R = 10.$	$\Delta R = 50.$
1	MSS	24.	12.	2.2
	TM	5.9	3.0	.55
2	MSS	35.	18.	3.5
	TM	2.0	1.1	0.2
3	MSS	56.	28.	5.7
	TM	2.3	1.1	0.2
4	MSS	8.9	4.4	.89
	TM	1.6	0.8	0.16

 $\Delta R$  in percent of full scale

## **APPENDIX H**

### **BAYESIAN CLASSIFIER SIMULATION RESULTS**

## APPENDIX H

### BAYESIAN CLASSIFIER SIMULATION RESULTS

A Monte Carlo simulation of an optimal (i.e. Bayesian maximum likelihood) classifier has been performed in order to obtain an estimate of the upper bound for performance of automatic crop classification algorithms. The sensitivities of the accuracy bound to various system and scene parameters are presented in Figures H-1 to H-6.

#### SIMULATION VARIABLES

I BAND	-	number of dimensions in the classifier feature space.
I BIT	-	number of bits per band used to represent sample signatures.
PS	-	pixel size
FS	-	field size
$\sigma_N$	-	standard deviation of system noise expressed as percent of dynamic range
$\sigma_F$	-	standard deviation of crop signature within a particular field
$\sigma_C$	-	standard deviation of crop signature encompassing many fields, soil types, crop varieties, etc.
TERR	-	classifier training error rate

#### NOTES

1. Curves labeled MSS and TM were obtained using the following "nominal" parameter values

	<u>MSS</u>	<u>TM</u>
IBAND	4	7
IBIT	7	9
PS	80.m	30.m
$\sigma_N$	5%	1%
$\sigma_F$	(individual crop standard deviation from CITARS Study)	
$\sigma_C$	7%	7%
TERR	.01	.01

2. Using crop signature statistics from Lee County, Illinois, and Shelby County, Indiana, high correlation between simulation results (optimal classifier) and the LARSYS algorithm results.

			Simulation Accuracy Bound	Larsys Accuracy
LEE 717	Training	( $\sigma_c = 0$ )	.77	.75
LEE 717	Test	( $\sigma_c = .02$ )	.65	.63
SHE 924	Training	( $\sigma_c = 0$ )	.73	.67
SHE 924	Test	( $\sigma_c = .02$ )	.53	.44

3. The results of the simulation should be interpreted to present relative performance measures rather than absolute accuracies due to the lack of information regarding crop signature statistics.

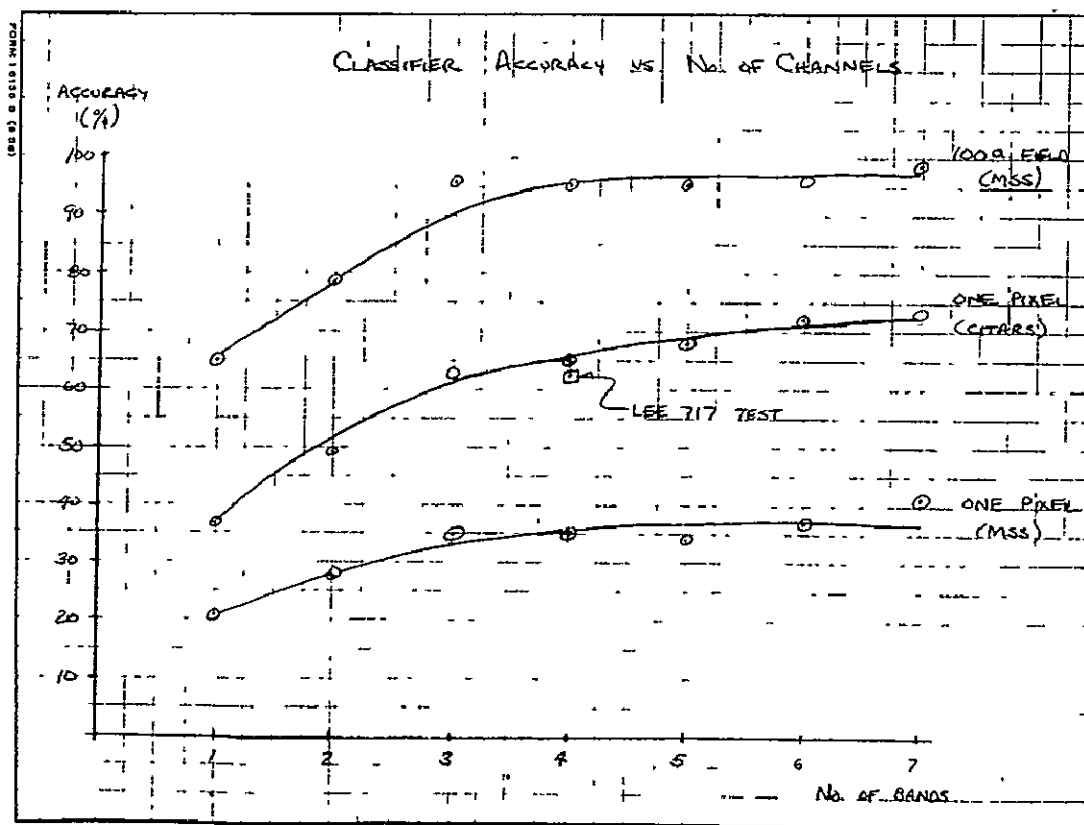


Figure H-1 Classifier Accuracy vs. Number of Channels

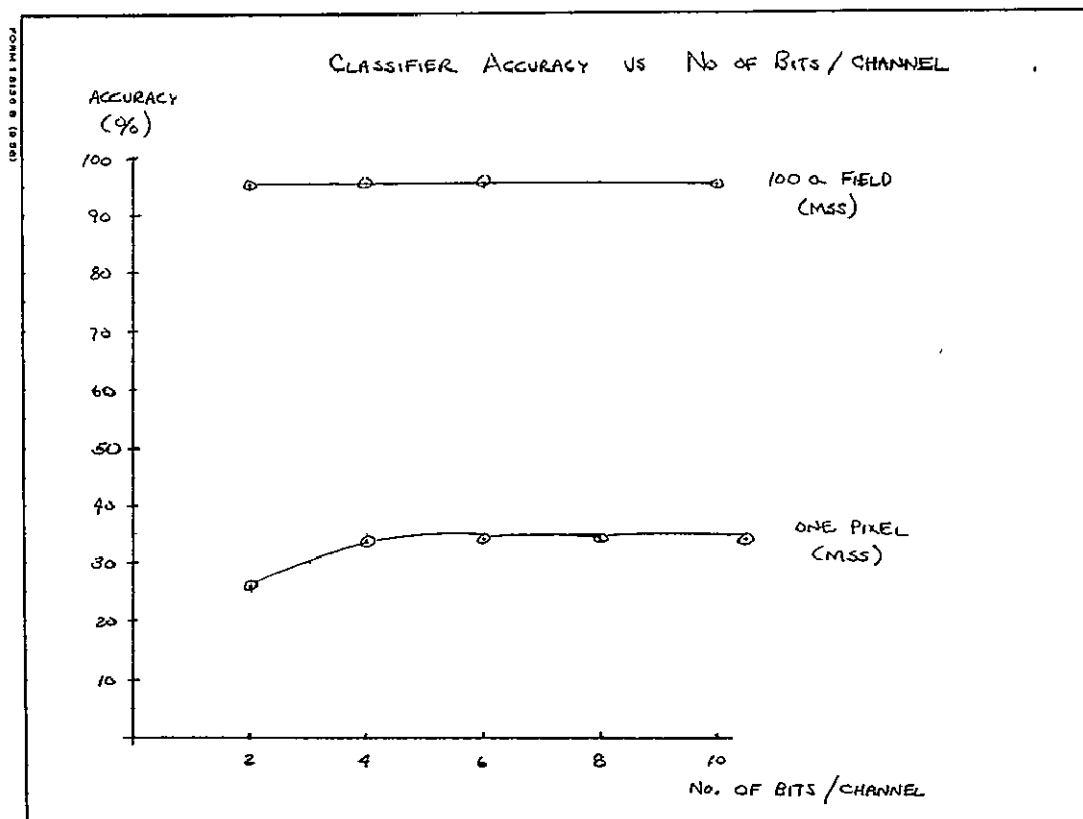


Figure H-2 Classifier Accuracy vs. Number of Bits/Channel

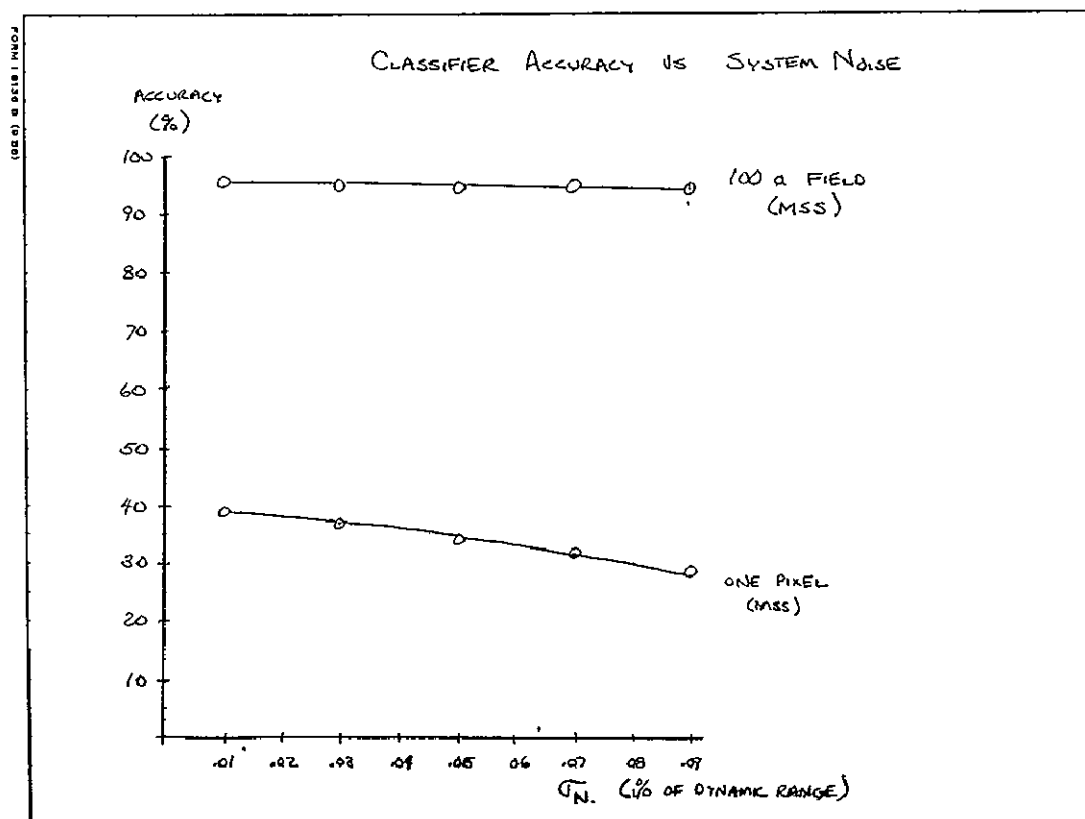


Figure H-3 Classifier Accuracy vs. System Noise



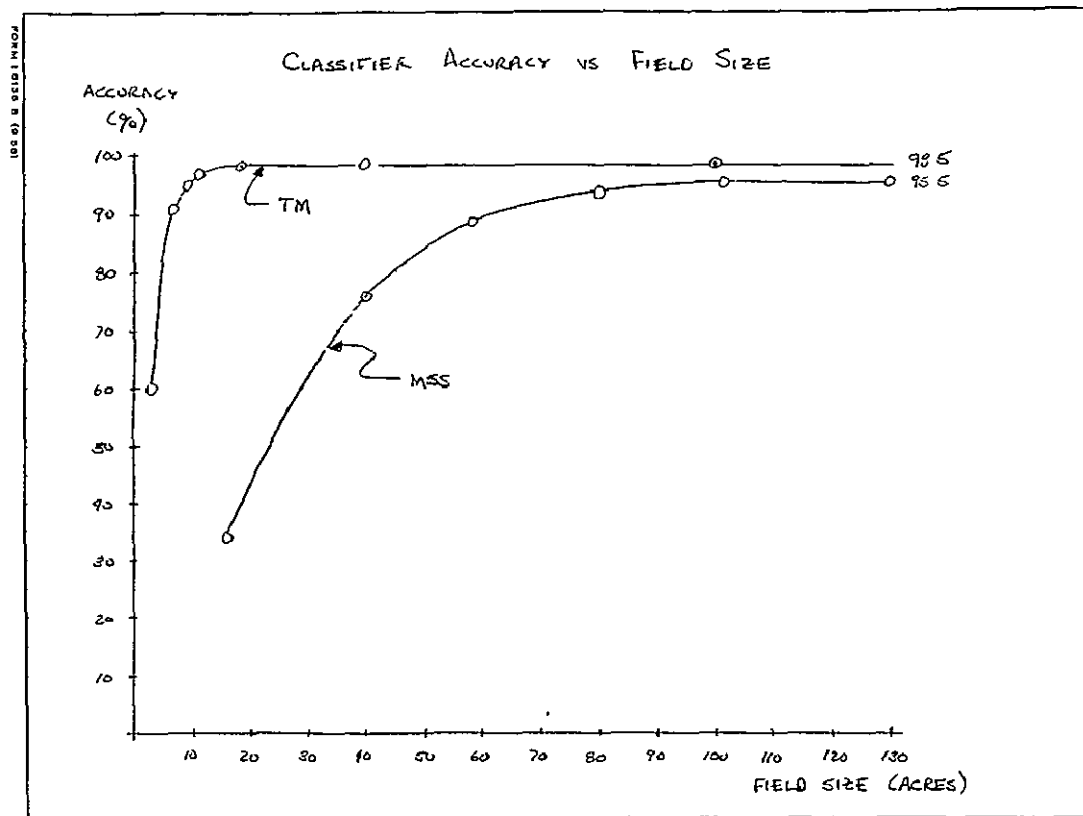


Figure H-4 Classifier Accuracy vs. Field Size

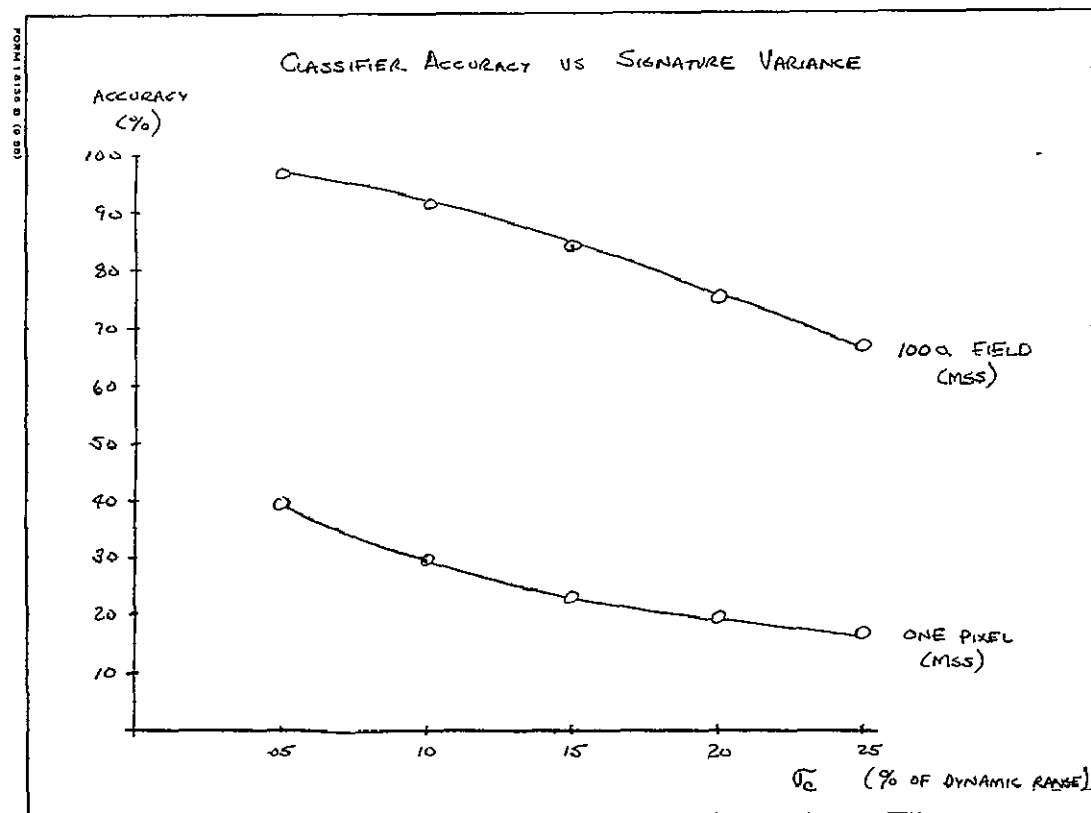


Figure H-5 Classifier Accuracy vs. Signature Variance

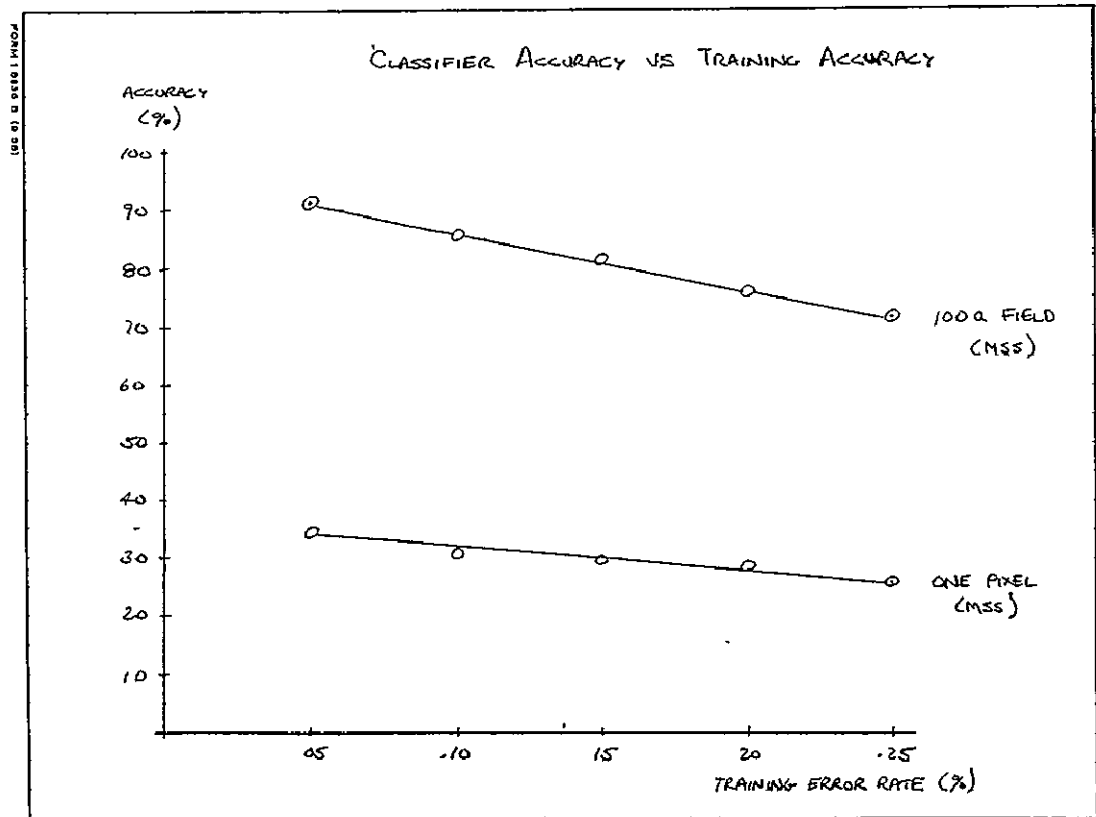


Figure H-6 Classifier Accuracy vs. Training Accuracy

**APPENDIX I**  
**RESIDUAL IMAGE PREPROCESSING ERRORS**

## APPENDIX I

### RESIDUAL IMAGE PREPROCESSING ERRORS

Preprocessing is the procedure in which a digital image is converted from its raw form to a form more suitable for analyses, and, in particular, extractive processing. The primary function of preprocessing is the removal of radiometric and geometric distortions found in the raw images.

Banding errors are radiometric errors prevalent in MSS type sensors, which have several detectors (six in MSS) in the same band scanning parallel, adjacent lines on the ground. Since it is not possible to match the detector responsivities perfectly, the resultant image shows bands of periodic light and dark scan lines. In LANDSAT 1 this distortion can be as great as ten quantum levels. To normalize the detector outputs, relative calibrations are performed at the end of every few scans. Pixel intensities are then corrected using a function of the form:

$$V_c = \frac{K \cdot V_{\max}}{\Delta R} \left[ \frac{V - r \cdot a}{q \cdot b} - R_{\min} \right] - r$$

where

$V_c$  = calibrated pixel value

$V$  = input pixel value (decompressed)

$V_{\max}$  = maximum pixel value (127 for 7 bit number)

$\Delta R$  =  $R_{\max} - R_{\min}$  = range of detector irradiance sensitivity limits

$a, b$  = offset, gain coefficients computed per scan line

$K, p, q, r$  = GFE constants characteristic of detector, expected to vary only infrequently

The gain and offset coefficients are computed from the functions:

$$a = \sum_n C_i V_i$$

$$b = \sum_n D_i V_i$$

where  $n$  = number of cal levels

$V_i$  = detector calibration samples

$C_i, D_i$  = GFE regression coefficients characteristic of each detector, derived from preflight calibrations and constant during normal sensor performance.

Geometric distortions arise both from random fluctuation in sensor operation and from predictable systematic sources. Examples of the former include spacecraft attitude, altitude and velocity fluctuations, and non-linear mirror scan profile. Examples of the latter are earth rotation and earth curvature effects. The systematic error sources can easily be modeled. The errors resulting from S/C attitude variations can be modeled if the vehicle has an attitude measurement system. LANDSAT does, but all S/C do not. If all the error sources can be modeled, a geometric correction function can be computed. Otherwise, a correction function can be generated by correlation of ground control points (GCP). Either way, the geometric correction procedure consists of applying the (two-dimensional) correction function to the image to perform a "rubber-sheet" correction. The corrected image is then resampled on a regular orthogonal grid to produce the final corrected image. When the error source model technique is used, GCP's are usually also employed for final "tweaking".

A Master Data Processing System (MDP) is presently being planned by NASA to perform this type of radiometric and geometric correction on LANDSAT images as well as digital images from future sensors. The pertinent specifications for MDP are:

Throughput                      10" bits/day ( $\sim$ 500 ERTS MSS scenes/day)

Radiometric correction  $< 2$  quantum levels over full range

Geometric correction  $< 1$  pixel 90% of the time  
with GCP

Temporal registration  $< 0.5$  pixel 90% of the time

The preprocessing requirements for the TOSS mission are strongly dependent on the ultimate classification system, and hence cannot be rigorously defined at this time. Several comments about it are, however, appropriate.

Clearly, radiometric correction of the highest degree of accuracy possible is required. The parametric relationship between the spread of the training and sample signatures and classification accuracy is presently being determined. It is clear, however, that broadening these signatures as a result of the extensive radiometric distortions will seriously degrade classification accuracy.

There is, at present, considerable activity in the area of radiometric correction of LANDSAT MSS images (1, 2, 3). The results of these activities seem to indicate that the MDP requirement of two quantum level radiometric correction accuracy is not now being met using the techniques described above. MSS data is compressed from a seven bit word to six bits on board the spacecraft, and is decompressed during ground processing using NASA furnished decompression tables. Radiometric correction, therefore, includes both decompression and banding correction. Corrected images, however, show significant residual banding, particularly in band four. In addition, histograms of corrected pixel intensities are not smooth functions, as one might expect. Instead they show pronounced discontinuities which vary with band, scene and time. The peaks on the histograms are typically separated by two quantum levels. It is believed that the residual radiometric errors do not reflect a basic limitation of the calibration technique. Instead, it reflects inaccuracies in the NASA furnished decompression tables and calibration constants. Clearly, the ability to achieve greater radiometric correction accuracy will require more thorough pre and in-flight sensor calibrations.

Residual errors in the geometric correction process have been investigated by IBM and TRW (4,5). Both groups have developed digital image correction systems similar in concept to GE's, although with different implementations. Of the two systems, IBM's is cruder, using nearest neighbor pixel resampling, while TRW uses their cubic convolution resampling technique, which is a four point approximation of a  $(\sin x)/x$  function. Both systems use modeling of systematic errors and GCPs to develop correction function, although TRW uses a Kalman filter technique for a more accurate modeling of vehicle attitude variations. Using these processes TRW reports a  $1\sigma$  residual geometric position error of 0.15 pixels, while IBM has errors of 0.5 - 1.0 pixels over most of the scene, increasing to 2 pixels in the corners of the scene. The scenes processed were U.S. urban centers for which accurate GCP's are easily available.

These results can be used to estimate the area measurement error for TOSS mission resulting from residual scene correction errors. The more accurate TRW results will be used since they more closely reflect the current state of the art. If it is assumed that the position error in each pixel is random, then a rectangular field of actual width W (in pixels) will have a measured width  $\bar{W}$  of

$$\bar{W} = W \pm \sqrt{2} \sigma_W$$

or

$$\bar{W} = (W, \sqrt{2} \sigma_W)$$

The  $\sqrt{2}$  factor results from the  $1\sigma$  uncertainty at each of the two ends of the width. If the actual height, of the field is H scan lines, then there will be H measurements of the width so the measured width then becomes

$$\bar{W} = (W, \sqrt{\frac{2}{H}} \sigma_W)$$

Similarly, the measured height is

$$\bar{H} = (H, \sqrt{\frac{2}{W}} \sigma_H)$$

and the measured area is

$$\bar{A} = \bar{W} \cdot \bar{H} = \left\{ W \cdot H \cdot \left[ \left( \frac{\partial A}{\partial W} \cdot \sigma_W' \right)^2 + \left( \frac{\partial A}{\partial H} \cdot \sigma_H' \right)^2 \right]^{\frac{1}{2}} \right\}$$

where  $\sigma_W'$  is the effective  $\sigma$  for the width measurement

$$\sigma_W' = \frac{\sqrt{2}}{\sqrt{H}} \sigma$$

and similarly for  $\sigma_H'$ . If the simplifying assumptions are made that the field is square,  $W = H$ ; and  $\sigma_W = \sigma_H$ , the area measurement reduces to

$$\bar{A} = (H^2, 2 \cdot \sqrt{H} \cdot \sigma)$$

The percent error is

$$E_A = \frac{2 \cdot \sqrt{H} \cdot \sigma}{H^2}$$

and, from TRW's results,  $\sigma = 0.15$ .

$$\therefore E_A = \frac{0.30 \sqrt{H}}{H^2}$$

This function is plotted as the solid line in Figure I-1 which shows percent

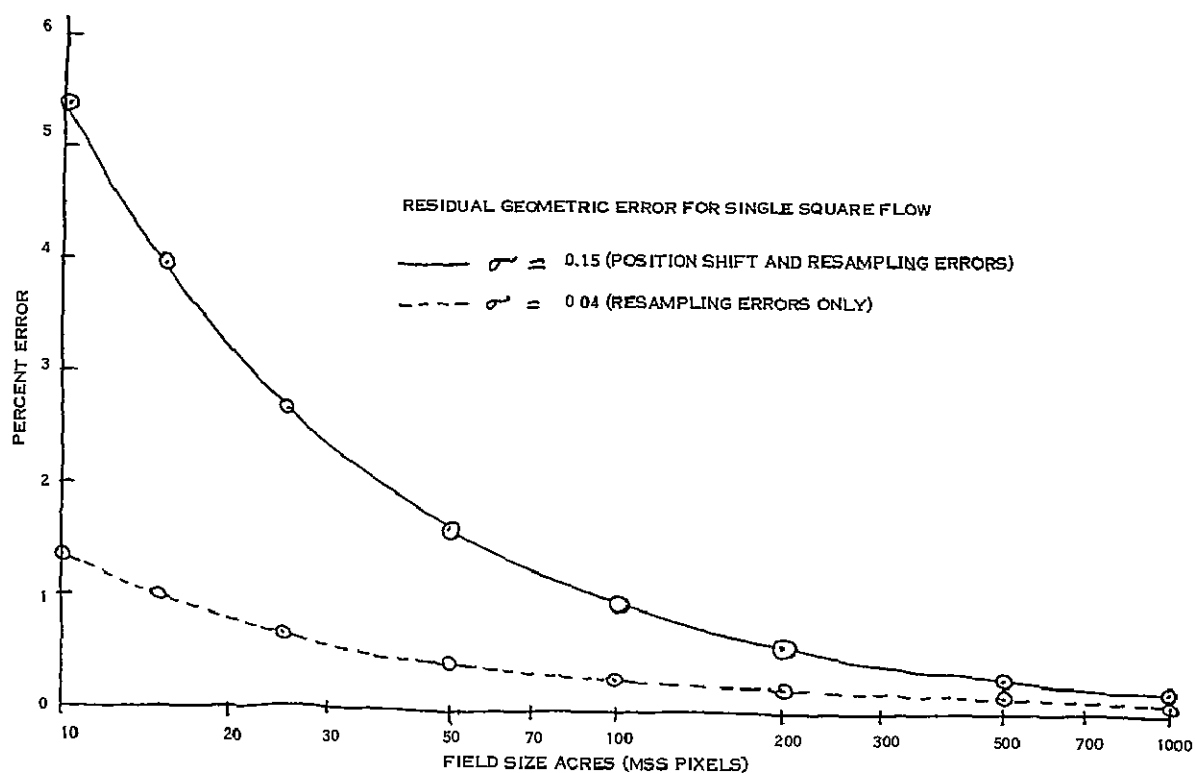


Figure I-1. Residual Geometric Error for a Single Square Field



error vs. field size. Although these errors are large for the small fields which are of maximum interest (2.7% for a 25 acre field), there are two additional considerations which reduce the errors to negligible levels. Firstly, these errors are for a single measurement of a single field. Clearly, crop surveys will be based on measurement of a large number of fields, the exact number to be determined by the sampling strategy. If N fields of roughly equal size are measured, the percent error is reduced by  $1/\sqrt{N}$ . Thus, if only 50 fields of 25 acres each are measured for a crop survey, the percent area error due to geometric correction is 0.38%.

The second, and more dominant factor in reducing the percent error is related to the randomness of the individual pixel errors. The foregoing discussion was based on the assumption that the position error of each pixel was random, with the  $\sigma$  as specified. The principal components of position error are errors in the correction function and errors in the resampling function. The largest contributor to position error is the correction function. But since the correction function is a continuous, slowly varying function, position errors over the relatively few pixels that form a field will be highly correlated; i.e., much of the error represents a uniform shift in position rather than a scale

---

change. Although scene shifts might affect the ability to register images, it does not affect the acreage measurement. Errors in the resampling function depend on the exact nature of the resampling function. IBM uses a crude nearest neighbor approach, in which the resampled value of a pixel is set equal to the value of that pixel which lies closest to it. This results in a resampling error having a uniform distribution over the limits -0.5 to + 0.5 pixels

which is given by

$$\sigma = \sqrt{\frac{(+0.5 - (-0.5))^2}{12}} = 0.29 \text{ pixels}$$

The TRW and GE systems use a more sophisticated cubic convolution technique in which the surrounding 16 points are weighted by a  $(\sin x)/x$  approximation. In that GE system, the  $(\sin x)/x$  function is not computed for each pixel; instead the pixel position is determined to the nearest 1/16 pixel and tabulated values of the function are applied. This represents a resampling error which also has a uniform distribution, but limits of -1/16 to +1/16 pixel, and

$$\sigma = \sqrt{\frac{\left(\frac{2}{16}\right)^2}{12}} = 0.04 \text{ pixel}$$

The area measurement error using the  $\sigma$  of 0.04 is shown as the dashed line in Figure I-1, and is well below 1% for field sizes of maximum interest. This factor, combined with the further decrease in acreage error resulting from multiple field measurements clearly makes the geometric correction error a negligible error source for the TOSS missions.

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**APPENDIX J**  
**TOSS FIELD SIZE STUDY**

## APPENDIX J

### TOSS FIELD SIZE STUDY

This appendix summarizes the TOSS field size study. The appendix is divided into two basic parts. The first part deals with the efforts of the study team to obtain data on field size distributions and field shapes from S190B imagery. In the second part, relevant results from other studies dealing with the field size question are discussed.

#### J.1 INTRODUCTION

Information pertaining to the distribution of field sizes over the globe is of basic importance in determining the system resolution required for a world crop survey mission. Unfortunately, however, statistical agencies in the U.S. as well as in all other countries have not made it a practice of collecting and publishing such data.

Other studies have attempted to circumvent this problem by resorting to the use of surrogate data -- principally, data on the sizes of holdings. Clearly, however, data pertaining to the distribution of holding sizes do not address the proper system question, and their use is likely to result in the derivation of improper conclusions.

Recognizing this fact, the study team opted to follow a more difficult, but potentially more rewarding type of approach -- that of deriving field size data from image analysis. In this connection, Landsat imagery was first examined because of the availability of coverage for most of the world. However, visual inspection of Landsat frames covering the major crop producing areas of the world resulted in the conclusion that except in the cases of certain areas in the western U.S. field boundaries were not distinct enough to permit accurate mensuration of field sizes.

Subsequently, the study team decided to attempt to utilize imagery generated by the S190A and S190B cameras on Skylab missions 2, 3 and 4. This imagery was made available by the Principle Investigator Management Office (PIMO) at NASA/JSC.

The S190A imagery was the first to be examined. This imagery is on 70 mm transparencies, and when viewed under 16X magnification it gave the appearances of having about the same resolution as a Landsat 9 1/2" enlargement. Thus, the conclusion was reached that this imagery would be of only marginal usefulness in making field size measurements.

Given this result, the only imagery inspected in detail was that from the S190B. The analysis of this imagery was carried out in two phases, and was correlated with inputs obtained from other studies bearing upon the field size question. The details of this effort and the inputs obtained from other studies are discussed in the following sections. A summary listing of the field size distributions presented in this appendix is given in Table J-0.

## J.2 ANALYSIS OF S190B IMAGERY

### J.2.1 FIRST PHASE

Imagery from the S190B is on 5" transparencies having a useable area of 4.5" x 4.5", and a nominal scale of 1" = 13.1 nautical miles (4.5" = 59 nautical miles). At the time the S190 imagery was first reviewed (June 1974), PIMO was able to provide detailed catalogs for the Skylab 2 and 3 missions which cross-referenced film magazine and frame numbers to geographical place names. Also available for these missions were lists which were indexed by both pass number and frame number, with specific geographic coordinates given for each frame. For the Skylab 4 mission, however, the only available catalog merely listed approximate geographic information for only 1 out of every 20 or 30 frames on a pass. Since the exposure cycle of the camera was not consistent (it varied from 10% to 60% overlap), it would not have been possible to identify frame locations from Skylab 4 imagery without carrying out some very time-consuming calculations. During the Skylab 2 mission, the S190B was only used over the U.S. For these reasons, the analysis of the S190B imagery was initially restricted to only that which was generated during the Skylab 3 mission.

Not counting the U.S., there are 13 countries which account for 5% or more of the world output of the crops selected in this TOSS study. These countries are shown in Table J-1. The first step in the analysis was to locate imagery for these countries. The results of this search are summarized in Table J-2, and, as can be seen, no imagery was available for 6 of the countries (China and the U.S.S.R. being among these), and some of the available imagery proved to be unuseable.

Given the results of this search, it was necessary to review imagery from several other countries and from several locations in the U.S. Table J-3 shows the frame locations of all of the areas which were finally analyzed. In each of the frames which were analyzed, one or two segments of intensive fields within each of these segments were then measured under 8 x magnification; the smallest field measureable was estimated to be 6.8 hectares (17 acres). The resulting distributions are shown in Figures J-1 and J-2 (note that the data are plotted as a cumulative percentage of total field area contained in fields of size greater than 6.8 hectares and larger numbers).

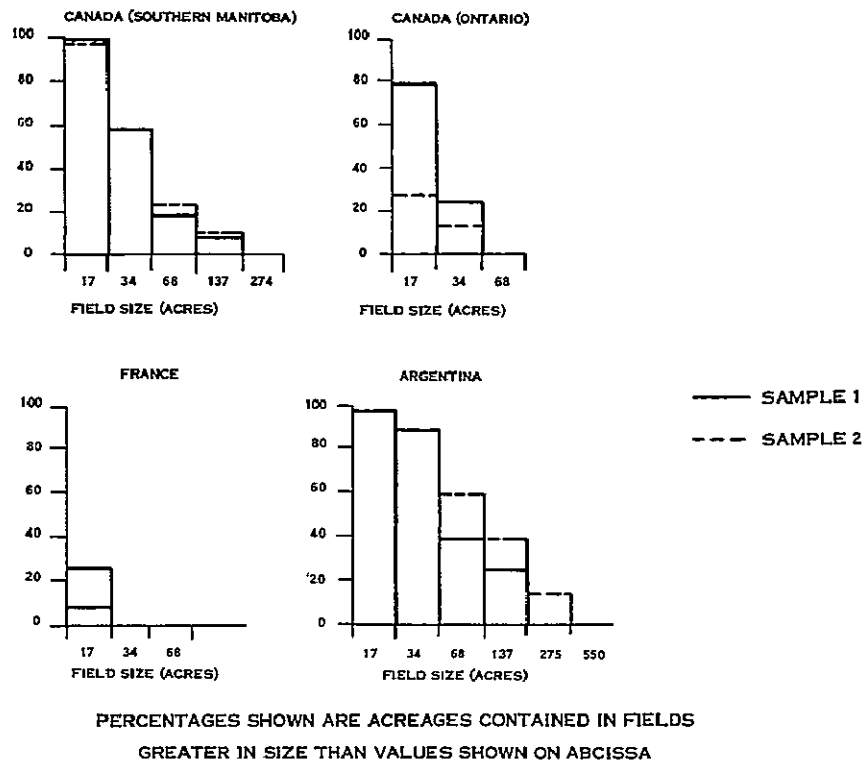


Figure J-1. Field Size Distributions as Measured in S190B Imagery for Selected Areas

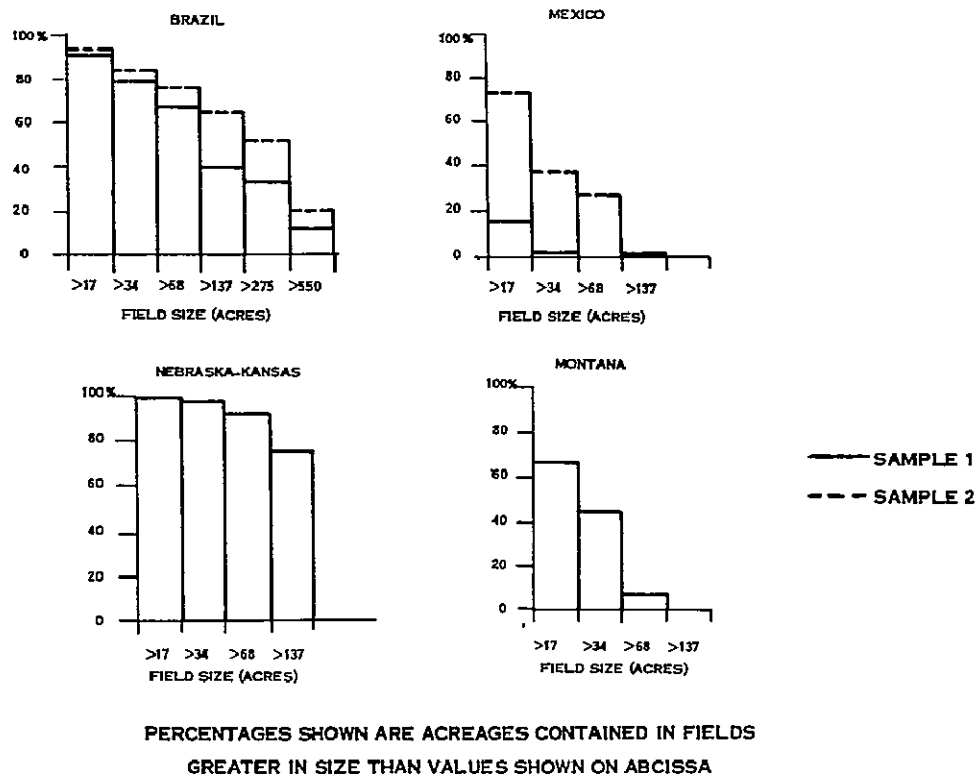


Figure J-2. Field Size Distributions as Measured in S190B Imagery for Selected Areas

Table J-0. Summary of Field Size Distributions

Appendix J Figure No.	Location	Source	Distribution Type	Remarks
J-1	Canada (S. Manitoba)	S190B	Area	All Fields
J-1	Canada (Ontario)	S190B	Area	All Fields
J-1	France	S190B	Area	All Fields
J-1	Argentina	S190B	Area	All Fields
J-2	Brazil	S190B	Area	All Fields
J-2	Mexico	S190B	Area	All Fields
J-2	Nebraska-Kansas	S190B	Area	All Fields
J-2	Montana	S190B	Area	All Fields
J-3	France	S190B	Field	All Fields
J-4	Argentina	S190B	Field	All Fields
J-5	S. Dakota	S190B	Field	All Fields
J-6	Thailand	S190B	Field	All Fields
J-7	Canada	S190B	Field	All Fields
J-8	Mexico	S190B	Field	All Fields
J-9	Brazil	S190B	Field	All Fields
J-10	France	S190B	Area	All Fields
J-11	Argentina	S190B	Area	All Fields
J-12	S. Dakota	S190B	Area	All Fields
J-13	Thailand	S190B	Area	All Fields
J-14	Canada	S190B	Area	All Fields
J-15	Mexico	S190B	Area	All Fields
J-16	Brazil	S190B	Area	All Fields
J-17	Salton Sea, Calif.	S190B	Area	All Fields
J-20	S. Dakota, CRD No. 6	Von Steen	Area	Corn
J-21	S. Dakota, CRD No. 6	Von Steen	Area	Oats
J-22	S. Dakota, CRD No. 6	Von Steen	Area	Soybeans
J-23	S. Dakota, CRD No. 6	Von Steen	Area	Spring Wheat
J-24	S. Dakota, CRD No. 6	Von Steen	Area	Barley
J-25	S. Dakota, CRD No. 6	Von Steen	Area	Winter Wheat
J-26	S. Dakota, CRD No. 6	Von Steen	Area	Total Wheat
J-27	S. Dakota, CRD No. 6	Von Steen	Area	All Crops
J-28	Kansas, CRD No. 7	Von Steen	Area	Corn
J-29	Kansas, CRD No. 7	Von Steen	Area	Oats
J-30	Kansas, CRD No. 7	Von Steen	Area	Barley
J-31	Kansas, CRD No. 7	Von Steen	Area	Winter Wheat
J-32	Kansas, CRD No. 7	Von Steen	Area	Rye
J-33	Kansas, CRD No. 7	Von Steen	Area	All Crops
J-34	Missouri, CRD No. 9	Von Steen	Area	Barley
J-35	Missouri, CRD No. 9	Von Steen	Area	Rye
J-36	Missouri, CRD No. 9	Von Steen	Area	Corn
J-37	Missouri, CRD No. 9	Von Steen	Area	Oats
J-38	Missouri, CRD No. 9	Von Steen	Area	Winter Wheat
J-39	Missouri, CRD No. 9	Von Steen	Area	Soybeans
J-40	Missouri, CRD No. 9	Von Steen	Area	All Crops
J-41	S. C. Idaho	Von Steen	Area	Corn
J-42	S. C. Idaho	Von Steen	Area	Oats
J-43	S. C. Idaho	Von Steen	Area	Barley
J-44	S. C. Idaho	Von Steen	Area	Winter Wheat
J-45	S. C. Idaho	Von Steen	Area	Spring Wheat
J-46	S. C. Idaho	Von Steen	Area	Total Wheat
J-47	S. C. Idaho	Von Steen	Area	All Crops
J-48	Williams, N. Dakota	LANDSAT P.I.	Area	All Fields
J-49	Williams, N. Dakota	LANDSAT P.I.	Area	Wheat
J-50	Williams, N. Dakota	LANDSAT P.I.	Area	All Non-Wheat Fields
J-51	Melfort, Sask.	LANDSAT P.I.	Area	All Fields
J-52	Melfort, Sask.	LANDSAT P.I.	Area	Wheat
J-53	Lee, Ill.	CITARS	Area	All Fields



## J.2.2 SECOND PHASE

Subsequent to the completion of the effort discussed above, the decision was made to extend the analysis by:

- 1) increasing the number of sample agricultural areas for the countries which had been examined in the previous phase,
- 2) including sample areas from some additional countries;
- 3) increasing the precision of field size measurements; and
- 4) dealing with the question of field shape.

Table J-1. Selected TOSS Countries

Countries Accounting for 5 Percent or More of World Output of Crops*	
Brazil	Japan
Canada	Mexico
China	Nigeria
France	Pakistan
India	Poland
Indonesia	U. K.
	U. S. S. R.

\*Not counting the U. S.

The countries dealt with in this analysis are as follows:

Argentina	Japan*
Canada	Mexico
Brazil	Thailand
France	U. S.

Table J-4 presents information pertaining to the agricultural areas, specific test sites, and S190B imagery which were subjected to analysis.\*\* The imagery was viewed through a binocular microscope mounted on a Richards light table. The magnification capability of the scope ranged from 5X to 30X. For this task, 10-15X power was found to be the most useable for measurement purposes. A 30X magnification provided more detail; however, boundaries between most fields were unrecognizable at this scale.

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\*No distributions were developed for Japan since most fields were too small to measure.

\*\*By the time the second phase of the analysis had begun, the cataloging for imagery from Skylab mission 4 had been brought up to the same level of detail as that for the imagery from Skylab missions 2 and 3. This imagery therefore became available for use in the analysis.

Table J-2. Availability of S190B Imagery of Important Crop Areas Outside U.S.

Country	S190B Imagery
U S S R	None
CHINA	None
CANADA	Extreme South only - 4 Passes
ENGLAND	None
FRANCE	3 Passes
NIGERIA	Solar Intercept Pass only - not calibrated
POLAND	None
INDIA	None
PAKISTAN	None
JAPAN	7 Frames from 1 Pass - all 50% to 100% Cloud Cover
INDONESIA	1 Pass over Borneo - 80% + Cloud Cover No Fields Visible
BRAZIL	Several Passes - 1 Useable
MEXICO	Several Passes - 1 Useable

Table J-3. Location of "Field Size" Images

Place	Location*	
	Longitude	Latitude
Brazil	23.31 7S	52:43 2W
Mexico	20 44 3N	100:2 9W
France	43:34N	2:47. 5E
Canada - S Manitoba	49.12 2N	99:13. 6W
Canada - Ontario	44 2N	77. 7W approximate
Nebraska - Kansas	40:4. 1N	101.30 6W
Montana	47:41 3N	104 8. 1W
Argentina	32:31. 9S	62 40 8W

\*Coordinates of image center

Table J-4. Field Size Areas and Test Sites

<u>Country</u>	<u>Area</u>	<u>Mag/Frame</u>	<u>Test Sites</u>		<u>NUMBER OF FIELDS MEASURED (APPROX.)</u>		
			<u>Per</u>	<u>Frame</u>	<u>Test Site</u>	<u>Per Test Site</u>	<u>Per Country</u>
					<u>Size (In)</u>	<u>Per Frame</u>	
Argentina	Bell Ville	84/337	2			144/216	583
Argentina	Col. Pringles	84/189	2			101/122	
Canada	Souris R.	88/237	2	.3	179/232	401	
Canada	Frenchman R.	83/127	2	.3	187/177	364	990
Canada	Pembina R.	88/238	1	.3	225	225	
Brazil	Tubarao	84/223	2	.5	135/159	294	465
Brazil	R. Paranaparema	84/348	2	.5	69/102	171	
France	Marseilles	86/259	1	.3	74		451
France	Montpellier	87/339	1	.3			
Japan	Takanabe	89/394	4	-	MOST FIELDS TOO SMALL TO MEASURE		
USA (S.D.)	Mitchell	81/314	2		178/168	346	612
USA (S.D.)	Mitchell	85/399	2		184/75	266	
Thailand	Phet Buri	91/208	2	.3	305/66	371	607
Thailand	Nakhan	84/105	2	.3	162/74	236	
	Rafeitasima						
Mexico	Guanajuato	88/36	2	.3	154/162	316	
Mexico	Guanajuano	90/280	1	.3	169		1088

Measurements of fields were performed with an mm reticle having an accuracy of .1 mm. The reticle was placed directly over the top of the test site area in the imagery, and readings were made directly by viewing through the binocular scope. In instances where the majority of field sizes averaged less than .1 mm per side, the readings were made to an accuracy of .05 mm.

All measurements of field sizes were made initially in millimeters or portions (tenths) of a millimeter. Subsequently, these readings were converted to miles and then to acres.

In tabulating the measurements, the field size classes shown in Table J-5 were used. After being tabulated, the data were then plotted as shown in Figures J-3 to J-17. Note that the data for each of the areas are plotted in two ways. Figures J-3 to J-9 show the percentages of the fields whose sizes are larger than X, where X (in acres) represents the largest field size in each one of the field size classes (see Table J-5).

Table J-5. Field Size Classes (in acres)

0 - 4.9	50.0 - 74.9
5.0 - 9.9	75.0 - 99.9
10.0 - 14.9	100.0 - 149.9
15.0 - 19.9	150.0 - 199.9
20.0 - 29.9	200.0 - 299.9
30.0 - 39.9	300+
40.0 - 49.9	

Figures J-10 to J-17 show the percentages of total acreage in fields larger than, X, where, as in the preceding case, X (in acres) represents the largest field size for each of the field size classes.

With respect to the question of field shape, Tables J-6 to J-12 present aspect ratio matrices for each of the areas considered. In each of the matrices, the figures in the boxes along the principal diagonal represent the number of fields having a ratio of 1:1 in length/width at each acreage size from .1 x .1 mm (2.2 acres) to 1.3 x 1.3 mm (376.5 acres). All other figures below the principal diagonal represent the numbers of fields having different ratios. The acreage values for these matrices are shown in Table J-13.

### J.3 RELATED STUDIES

In parallel with the effort discussed above, the TOSS study team also reviewed the findings of other studies dealing with the field size question. These studies are discussed below.

C-5

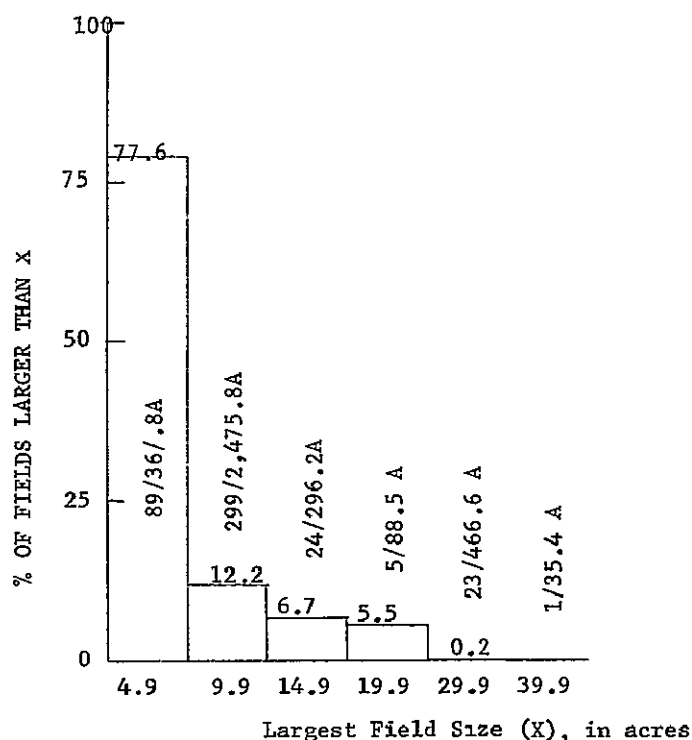


Figure J-3. Field Size Distribution - France

### J.3.1 LOCKHEED LANDSAT STUDY

The objective of this study (done by Lockheed for NASA/JSC) was to determine the distributions of field sizes within 8 countries.\*

For each of the foreign countries, selected fields were measured from Landsat color IR transparencies. A point grid (see Figure J-18) was placed over the imagery, and the fields located under the 36 points within the dashed line were measured. The resulting distributions are shown in Table J-14.

The study also presents ground truth data for selected areas in the U. S. ; however, the data only pertains to average field sizes and ranges of field sizes, and not to field size distributions per se. These data are shown in Table J-15.

\*The countries include: Australia, Argentina, Brazil, Canada, China, India, U. S. S. R., and U. S.

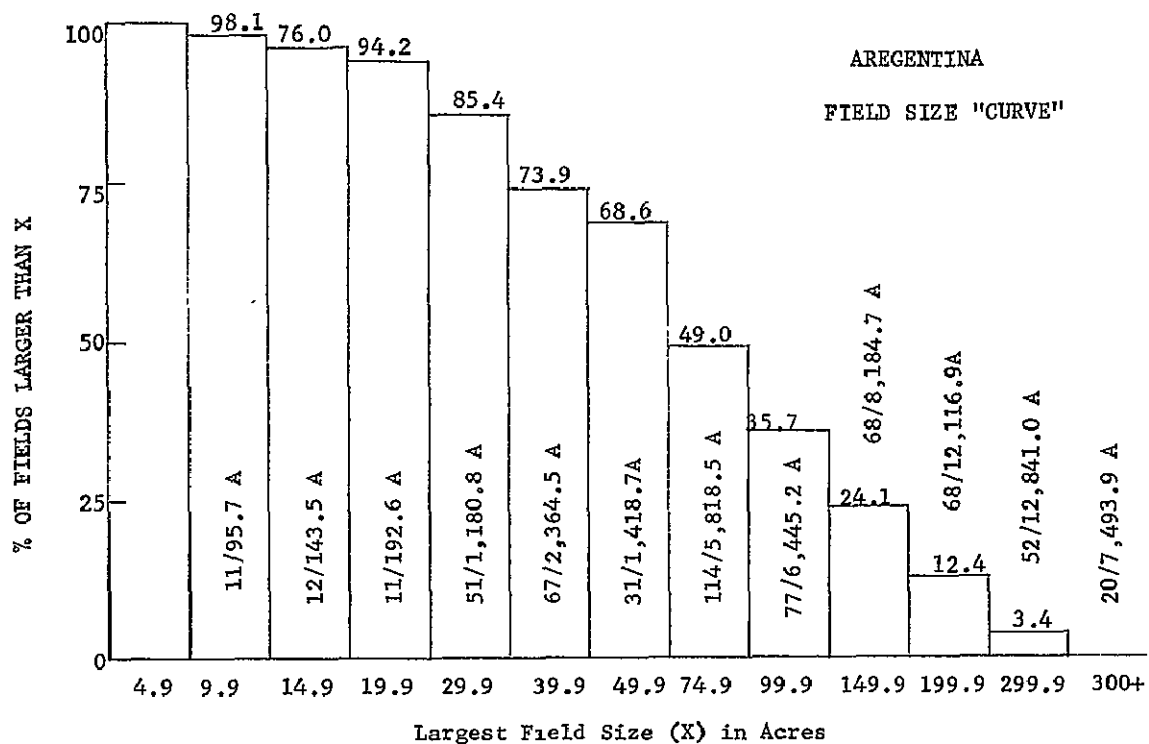


Figure J-4. Field Size Distribution - Argentina

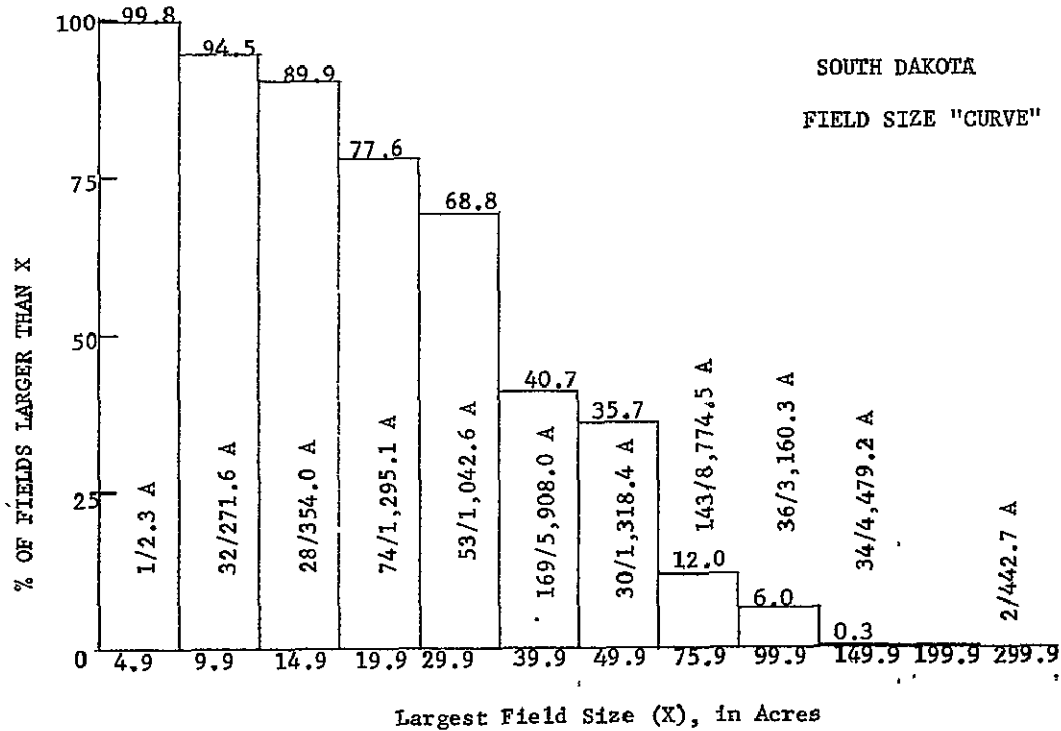


Figure J-5. Field Size Distribution - South Dakota

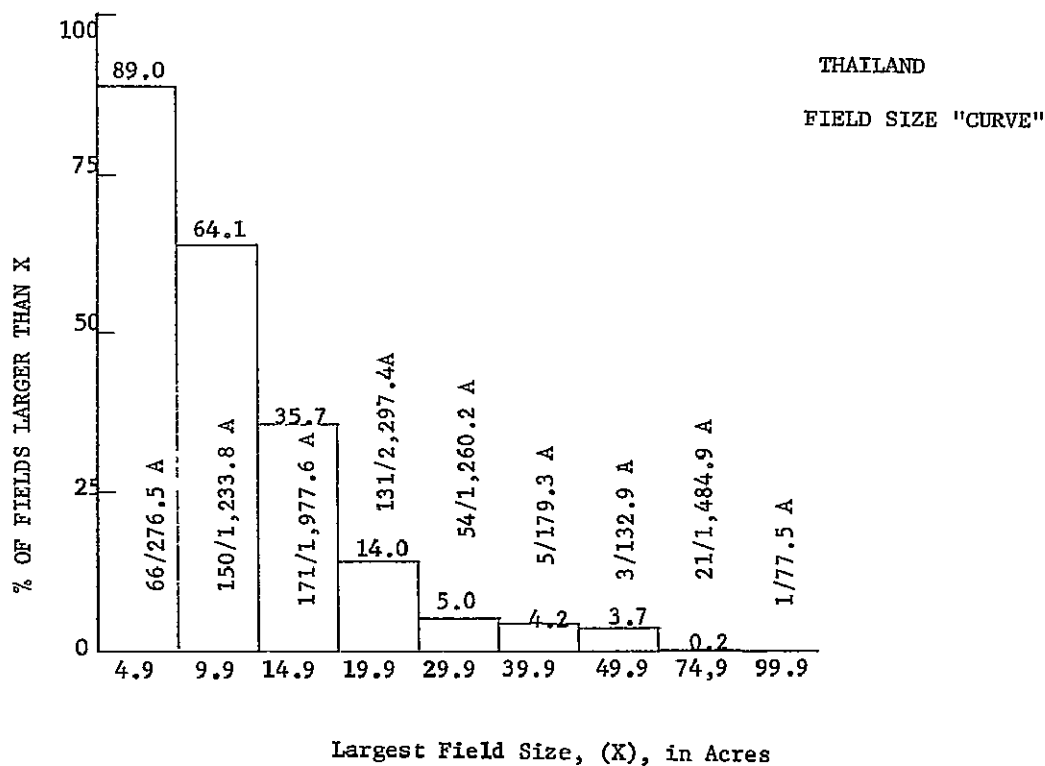


Figure J-6. Field Size Distribution - Thailand

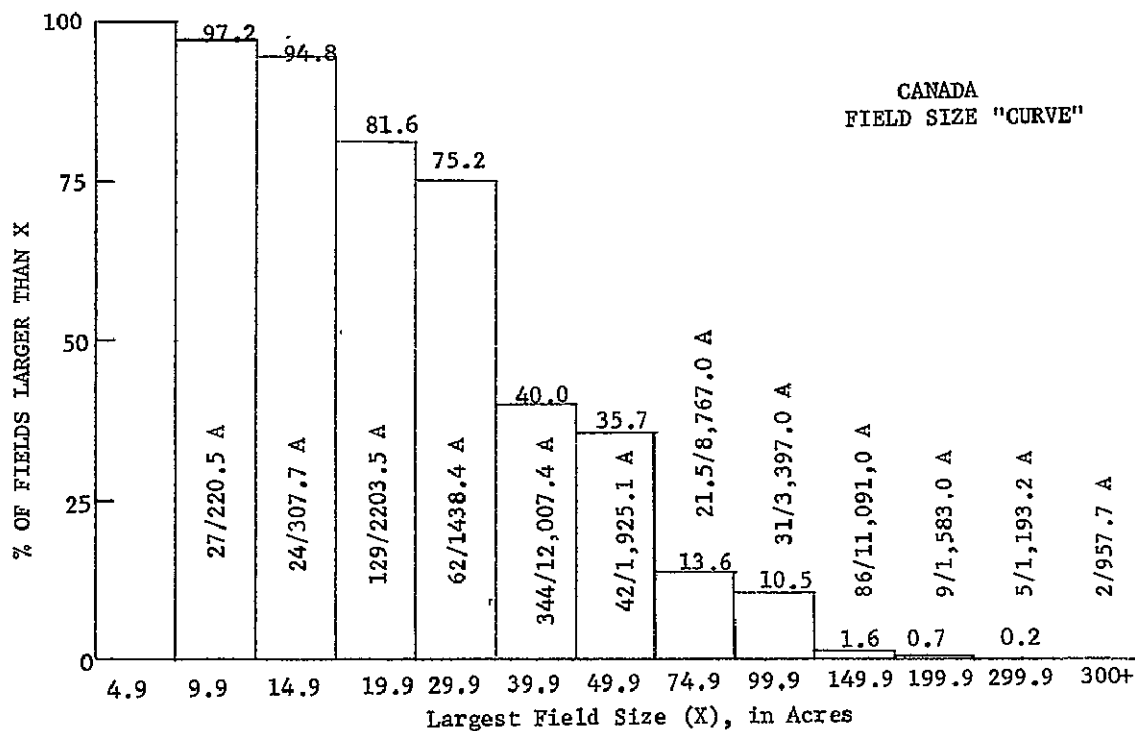


Figure J-7. Field Size Distribution - Canada

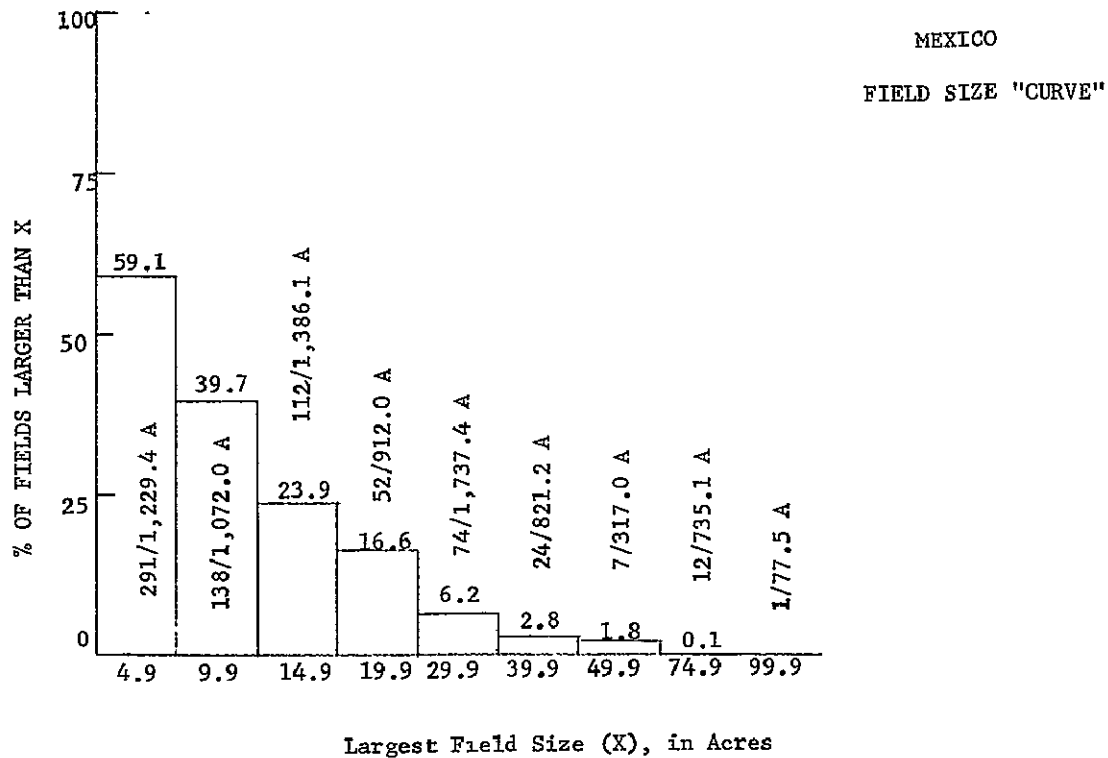


Figure J-8. Field Size Distribution - Mexico

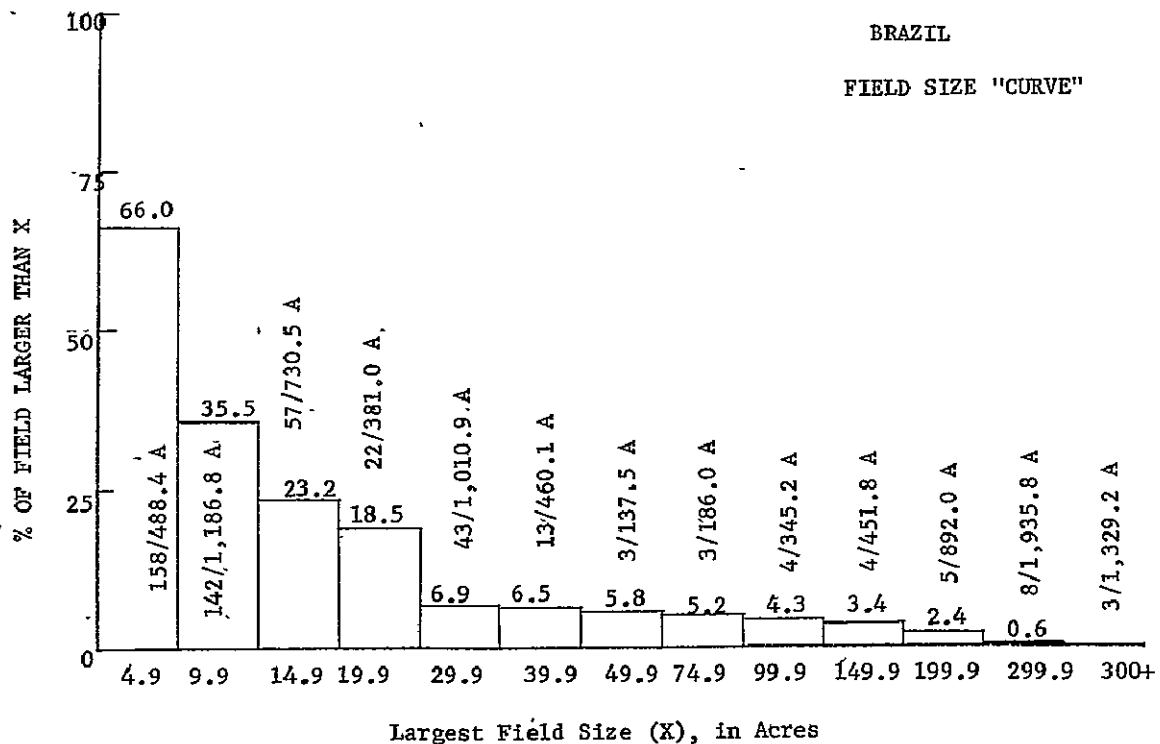


Figure J-9. Field Size Distribution - Brazil



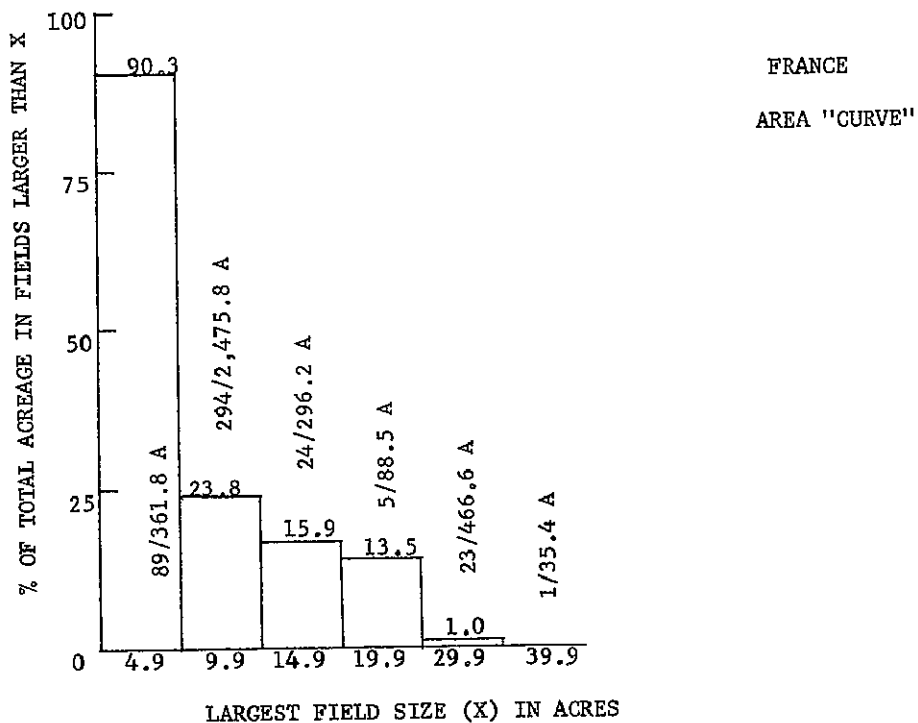
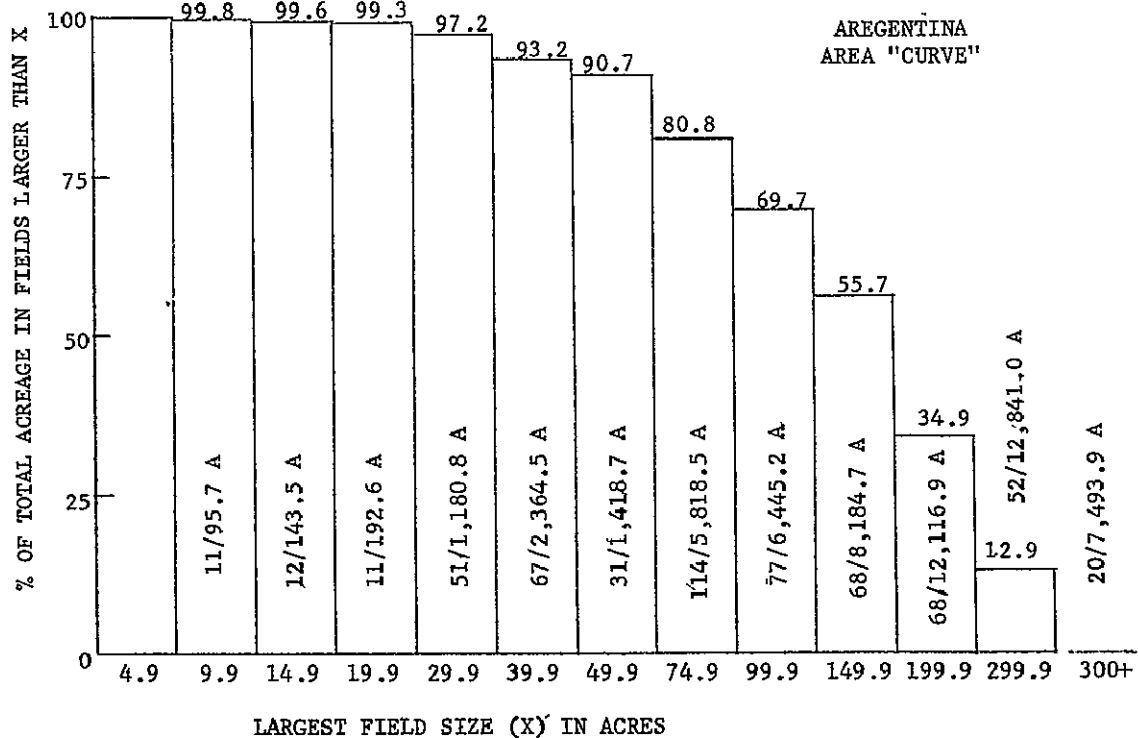


Figure J-10. Field Size Distribution (by Area) - France



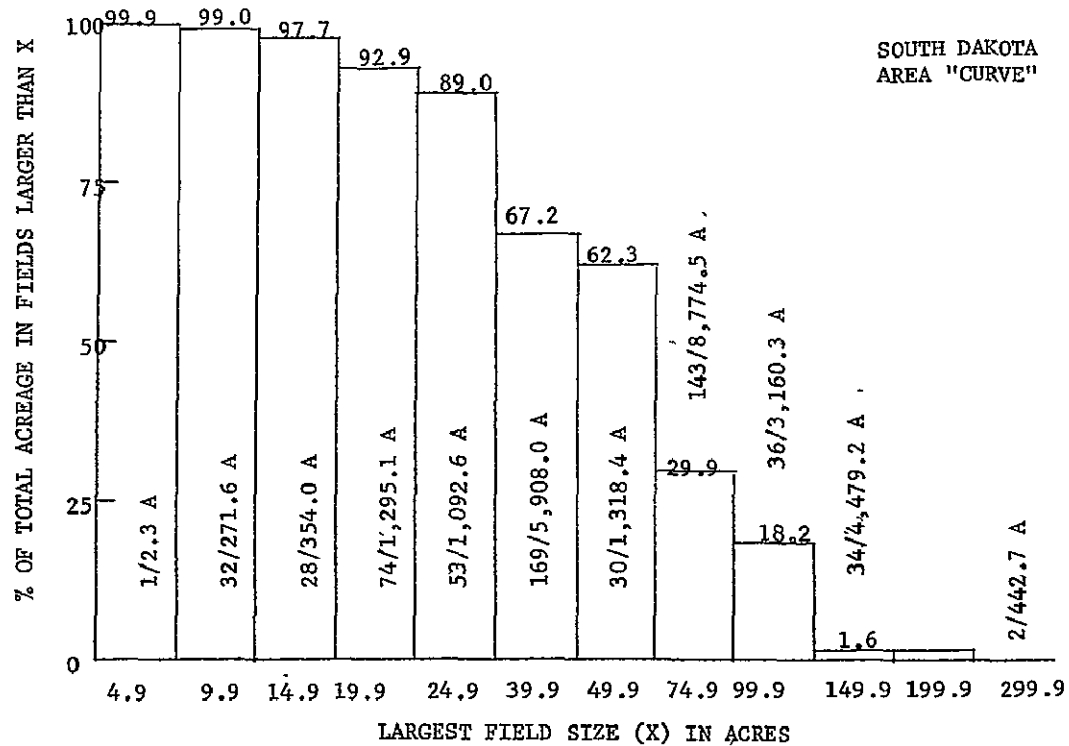


Figure J-12. Field Size Distribution (by Area) - South Dakota

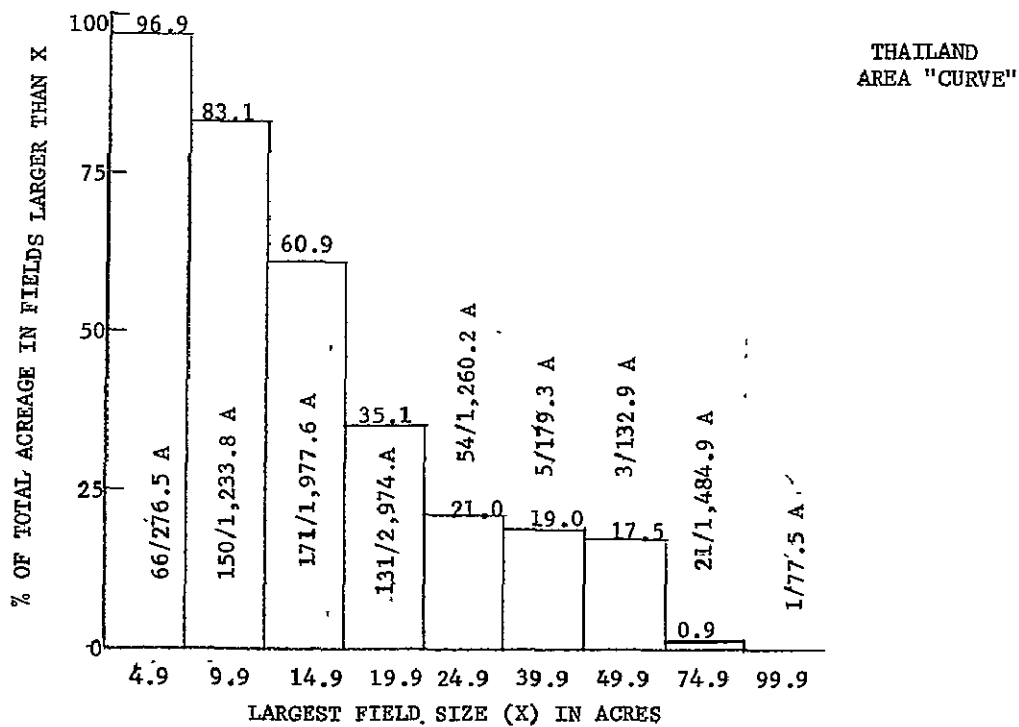


Figure J-13. Field Size Distribution (by Area) - Thailand

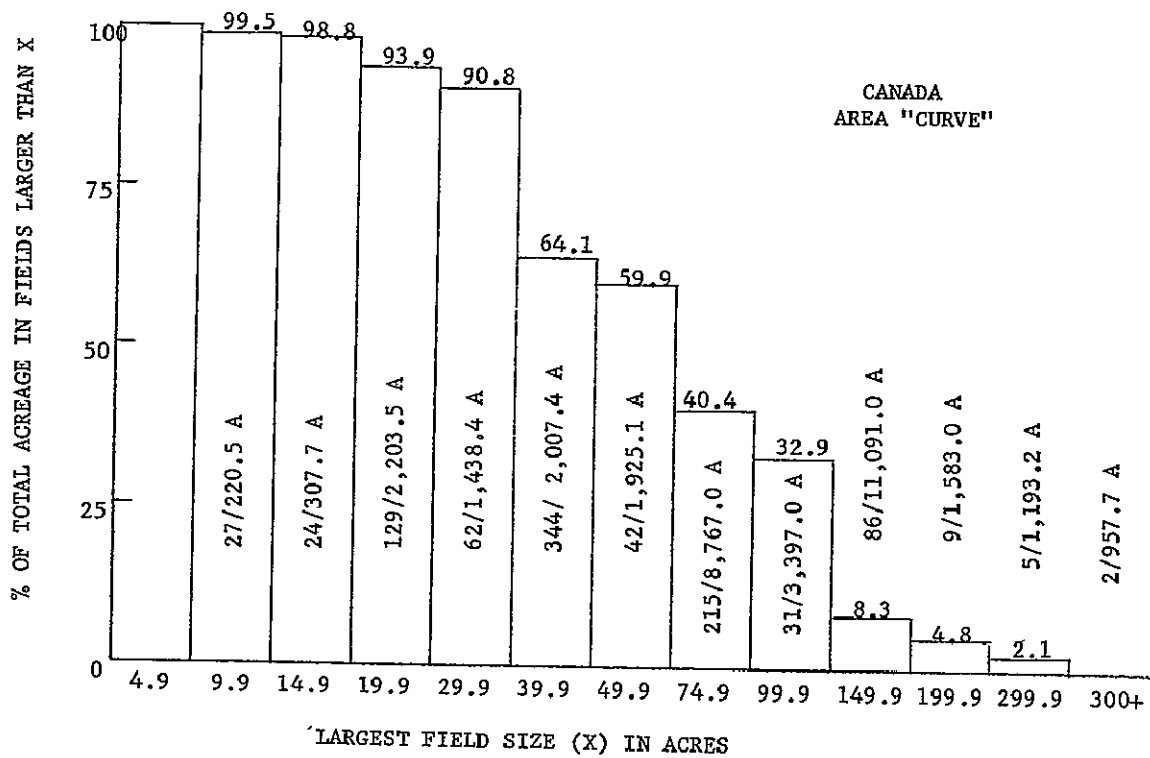


Figure J-14. Field Size Distribution (by Area) - Canada

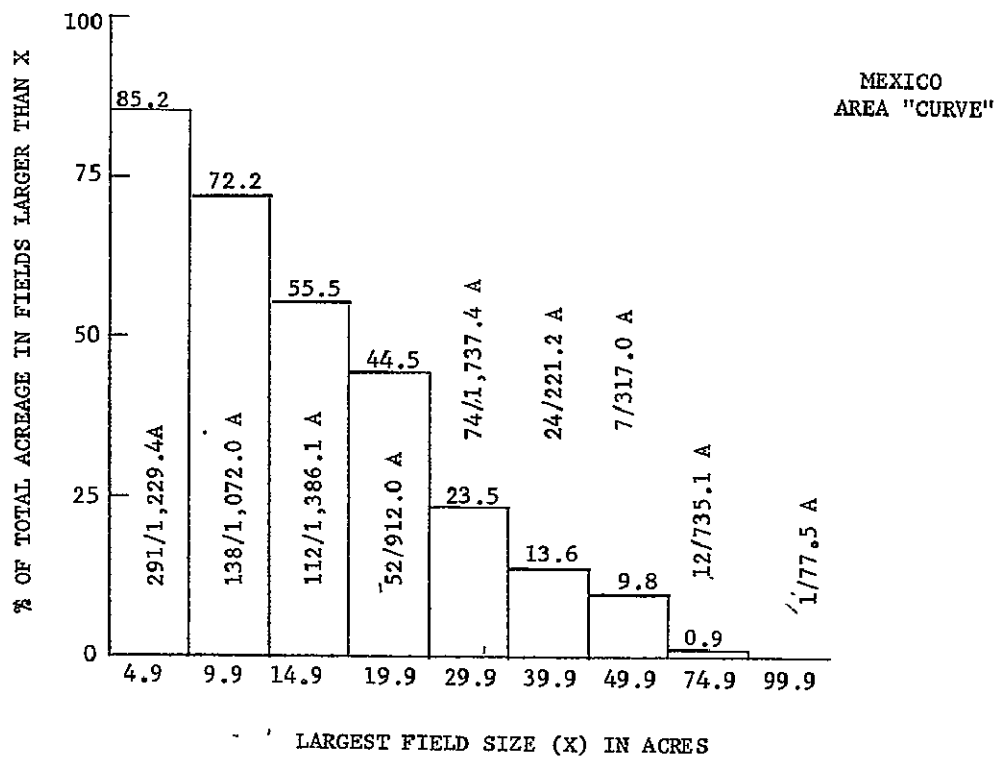


Figure J-15. Field Size Distribution (by Area) - Mexico

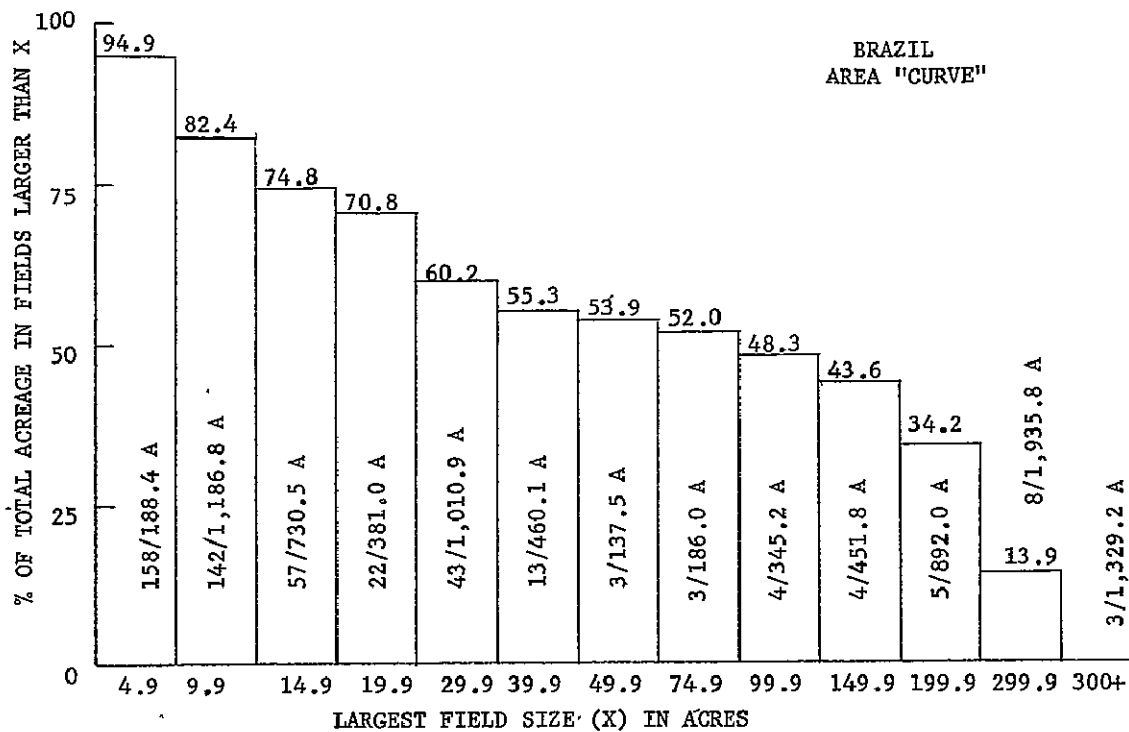


Figure J-16. Field Size Distribution (by Area) - Brazil

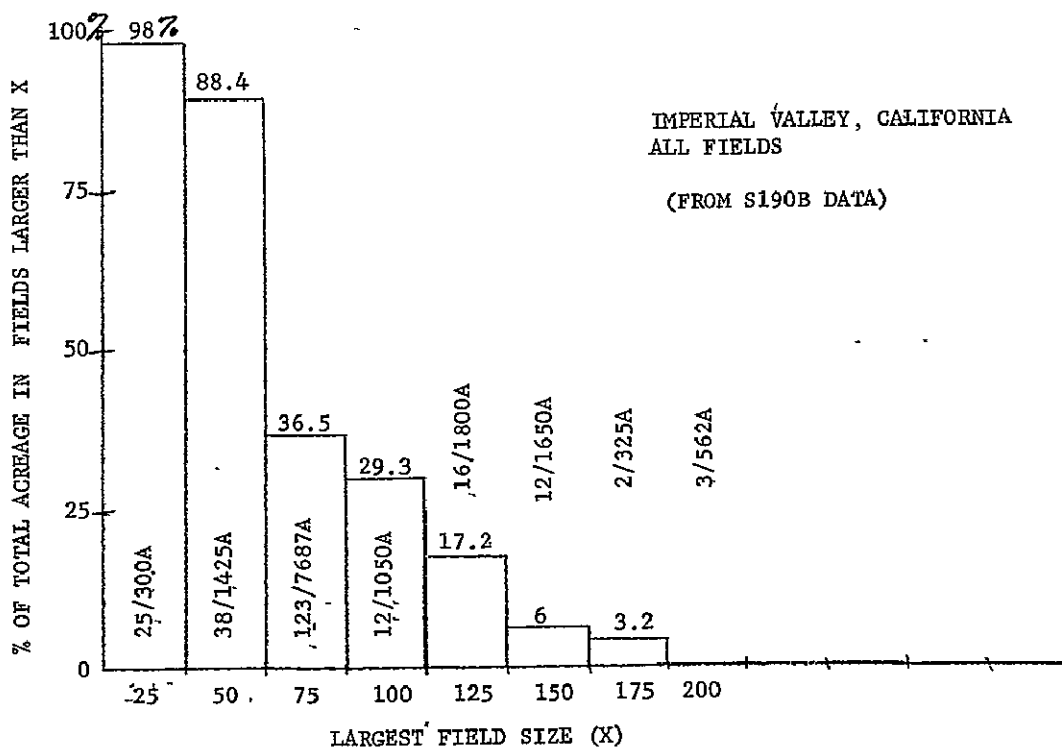


Figure J-17. Field Size Distribution (by Area) - Imperial Valley, Calif.

Table J-6. Aspect Ratio Matrix - Argentina

.826	1.4														0
.767	1.3													5	1
.708	1.2												2	1	4
.647	1.1											2	4	1	6
.577	1.0										3	15	8	4	1
.531	.9									16	4	5	2	1	4
.472	.8								6	8	10	7	3	3	0
.413	.7							7	2	2	2	2	6	1	0
.354	.6						33	8	12	10	2	8	5	4	5
.295	.5					29	32	13	5	7	9	2	3	0	2
.236	.4				15	10	17	15	7	6	4	2	4	0	0
.177	.3			11	3	23	13	15	3	3	4	4	1	0	1
.118	.2		10	4	10	17	14	11	4	3	4	3	1	0	0
.059	.1	0	0	1	0	7	1	1	0	0	1	2	0		0
		.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	1.1	1.2	1.3	1.4
		.059	.118	.177	.236	.295	.354	.413	.472	.531	.577	.647	.708	.767	.826

Table J-7. Aspect Ratio Matrix - Brazil

.767	1.3													0
.708	1.2												0	0
.647	1.1											0	0	0
.577	1.0										0	0	0	0
.531	.9									0	0	0	0	1
.472	.8								0	0	1	1	1	0
.413	.7							0	0	0	1	0	0	0
.354	.6						0	2	1	2	0	0	0	0
.295	.5					0	0	0	0	0	0	0	0	0
.236	.4			2	0	0	1	0	1	0	0	1	0	0
.177	.3		15	4	3	3	2	0	0	0	0	1	0	0
.118	.2		95	40	13	8	15	2	4	0	1	0	0	1
.059	.1	92	57	39	15	13	9	4	4	0	0	0	0	0
		.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	1.1	1.2	1.3
		.059	.118	.177	.236	.295	.354	.413	.472	.531	.577	.647	.708	.767

**Table J-8. Aspect Ratio Matrix - Canada**

[illegible]

**Table J-9. Aspect Ratio Matrix - France**

A hand-drawn graph showing the relationship between miles (mi) and minutes (mi) for a person walking. The x-axis is labeled "mi" and ranges from 0 to 1.3. The y-axis is labeled "mi" and ranges from 0.059 to 1.3. A series of points are plotted, showing a linear relationship. The points are: (0.1, 0.059), (0.2, 0.118), (0.3, 0.177), (0.4, 0.236), (0.5, 0.295), (0.6, 0.354), (0.7, 0.413), (0.8, 0.472), (0.9, 0.531), (1.0, 0.590), (1.1, 0.649), (1.2, 0.708), (1.3, 0.767). The points are connected by a dashed line.

[illegible][illegible]

Table J-12. Aspect Ratio Matrix - South Dakota

.767	1.3													0
.708	1.2											0	0	
.649	1.1										0	6	0	
.590	1.0									0	0	0	0	
.531	.9								0	0	0	0	0	
.472	.8							23	0	0	0	1	1	
.413	.7						5	1	0	0	0	0	0	
.354	.6					7	3	5	0	0	0	0	0	
.295	.5				5	1	2	20	0	0	0	1	0	
.236	.4			40	22	22	7	56	0	4	1	2	0	
.177	.3		8	17	13	11	9	49	0	1	1	0	0	
.118	.2	3	14	28	19	11	22	76	0	0	1	0	0	
.059	.1	1	0	5	22	8	8	7	39	0	0	0	1	0
mi	mm	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	1.1	1.2	1.3
mm		.059	.118	.177	.236	.295	.354	.413	.472	.531	.590	.649	.708	.767

Table J-13. Acreage for Elements of Aspect Ratio Matrices

.767	1.3													376.5
.708	1.2												320.8	347.5
.649	1.1											269.6	294.1	318.6
.590	1.0										222.8	245.1	267.3	289.6
.531	.9									180.5	200.5	220.6	240.6	260.7
.472	.8								142.6	160.4	178.2	196.0	213.9	231.7
.413	.7							109.2	124.8	140.4	155.9	171.5	187.1	202.7
.354	.6					90.2	93.6	106.9	120.3	133.7	147.0	160.4	173.8	
.295	.5				55.7	66.8	78.0	89.1	100.3	111.4	122.5	133.7	144.8	
.236	.4			35.6	44.6	53.5	62.3	71.3	80.2	89.1	98.0	106.9	115.8	
.177	.3		20.0	26.7	33.4	40.1	46.8	53.5	60.2	66.8	73.5	80.2	86.9	
.118	.2	8.9	13.4	17.8	22.3	26.7	31.2	35.6	39.7	44.6	49.0	53.5	57.9	
.059	.1	2.2	4.5	6.7	8.9	11.1	13.4	15.6	17.8	20.0	22.3	24.5	26.7	29.0
mi	mm	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	1.1	1.2	1.3
mi		.059	.118	.177	.236	.295	.354	.413	.472	.531	.590	.649	.708	.767



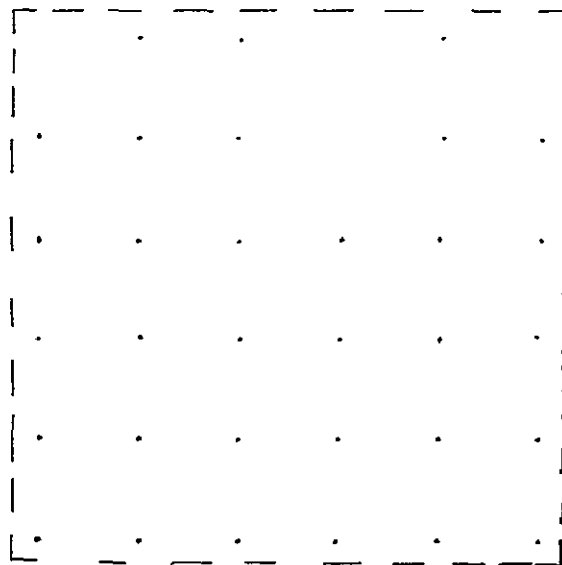


Figure J-18. Point Grid Utilized in Selecting Fields to Measure

### J.3.2 VON STEEN STUDY OF FOUR CROP REPORTING DISTRICTS

In 1972, the Statistical Reporting Service of the U.S. Department of Agriculture made a special study of field size information relating to several crops for particular Crop Reporting Districts (CRD's). In his study, Von Steen refers to the results of this study with respect to four areas: CRD 6 in South Dakota; CRD 7 in Kansas; CRD 9 in Missouri; and a four-county region in south central Idaho (Cassia, Jerome, Minidoka, and Twin Falls Counties). Figure J-19 presents a map showing the locations of these areas. The field size data for each of these areas are shown in tabular form in Tables J-16 and J-19. Although the data pertain to only a limited number of areas, they are particularly useful since they cover all of the crops selected in the TOSS study.

Figures J-20 to J-47 present selected portions of the above mentioned data in graphical form. For each crop shown for the four areas, the data are plotted as percentages of total acreage in fields larger than X, where X (in acres) represents the largest field size for each of the field size classes (the size classes are defined in Table J-5).

Table J-14. Field Size Distribution

Country- Region	Total /g -000 Ha	Total /g -000 Ha	Total /g -000 Ha	Total /g -000 Ha	Total /g -000 Ha	Total /g -000 Ha	Total /g -000 Ha	Total /g -000 Ha	Total /g -000 Ha
Australia									
Western Australia	(1972-73) 10,624.3	(1972-73) 2,137.4	-	-	10.5	36.8	47.4	5.3	-
S. Australia & Victoria	(1972-73) 10,479.6	(1972-73) 2,073.4	-	-	25.0	33.3	41.7	-	-
New South Wales & Queensland	(1972-73) 15,711.2	(1972-73) 3,171.1	-	-	15.4	23.0	38.5	15.4	7.7
Argentina	(1960)	(1973-74)							
Pampa	24,558.0	3,822.7	-	-	61.0	19.5	19.5	-	-
Brazil	(1967) 6,836.0	(1973) 3,100.0 (1967) 900.0	3.8	7.7	65.3	11.6	11.6	-	-
Canada	(1971) 54,054.4	(1971) 7,643.0	-	-	71.1	26.7	2.2	-	-
China									
North China Plain	(1958-59) 55,228.5	(1957) 14,200.3	91.1	5.9	-	3.0	-	-	-
Szechwan Basin	(1958) 7,664.4	(1957) 1,359.7	61.5	23.1	15.4	-	-	-	-
Western China	(1957-58) 12,020.3	(1956) 1,552.8	no imagery						
Manchurian Plain	(1959) 16,423.9	(1957) 972.0	-	18.2	81.8	-	-	-	-
Southeast China	(1957-58, 1959) 42,220.9	(1957) 21,219.2	97.0	3.0	-	-	-	-	-
India	1/(1970- 1971)	(1970-71)							
Punjab Plain	10,635.0	3,428.0	50.0	29.2	20.8	-	-	-	-
Ganges Flood Plain	41,325.0	7,583.0	76.5	14.7	8.8	-	-	-	-
Central Uplands	77,527.0	6,533.0	58.3	12.5	29.2	-	-	-	-
U.S.S.R.		2/(1971)							
Kazakhstan	N.A.	17,584.0	-	-	-	-	44.4	44.4	11.2
Western USSR	N.A.	8,289.9	-	-	29.5	47.0	23.5	-	-
North Caucasus	N.A.	5,672.2	No imagery						
Urals	N.A.	8,685.4	-	-	11.8	23.5	41.1	11.8	11.2
Central District	N.A.	4,162.2	-	-	78.6	14.3	7.1	-	-
Volga	N.A.	8,222.3	-	-	7.7	11.6	73.0	7.7	-
Western Siberia	N.A.	11,574.0	-	-	25.0	15.0	45.0	15.0	-

1/includes some double cropping

2/harvested area

\*stated as a percentile of the number of fields within the category

FROM JUNE 75 LOCKWOOD STUDY  
NAS 7-12200 AND ORDER 74-733

Table J-15. U.S. Field Size Data

Region State County	Test Site Area (Ha)	Number of Fields	Average Field Size (Ha)	Range in Field Size (Ha)
Corn Belt				
Indiana				
Madison	2330.989	250-270	8.092	2.0-41.0
Boone	2330.989	210-230	10.117	1.0-41.0
Shelby	2330.989	260-280	8.093	2.0-25.0
N. Great Plains				
North Dakota				
Burke	7769.964	210-230	22.257	2.0-65.0
Williams	7769.964	240-310	16.187	2.0-65.0
Divide	5179.976	NA	NA	NA
Montana				
Wall	3107.985	140-160	20.234	4.0-129.0
Liberty	5179.976	NA	NA	NA
Toole	5179.976	NA	NA	NA
Glacier	5179.976	NA	NA	NA
S. Great Plains				
Kansas				
Finney	7769.964	400-420	18.211	.8-65.0
Morton	7769.964	220-250	32.375	4.0-65.0
Saline	2330.989	150-170	12.141	2.0-49.0
Ellis	2330.989	150-170	16.187	2.0-57.0
Rice	2330.989	150-170	16.187	2.0-57.0
Texas				
Randall	2330.989	90-105	24.281	2.0-129.0
Deaf Smith	2330.989	160-175	14.164	3.0-65.0
Oldham	2330.989	55-65	42.492	4.0-129.0
Pacific Northwest				
Idaho				
Bannock	2330.989	80-90	22.258	2.0-53.0
Franklin	2330.989	295-315	6.070	1.0-16.0
Oneida	2330.989	60-70	36.428	4.0-65.0
Washington				
Whitman 1	2330.989	10-25	113.312	32.0-243.0
Whitman 2	2330.989	10-20	161.874	8.0-567.0
Whitman 3	2330.989	20-30	60.703	4.0-486.0

Source LACIL Intensive Test Site Assessment Report

FROM JUNE '75 LOCKHEED STUDY NAS 9-12200 JOB # 74-733

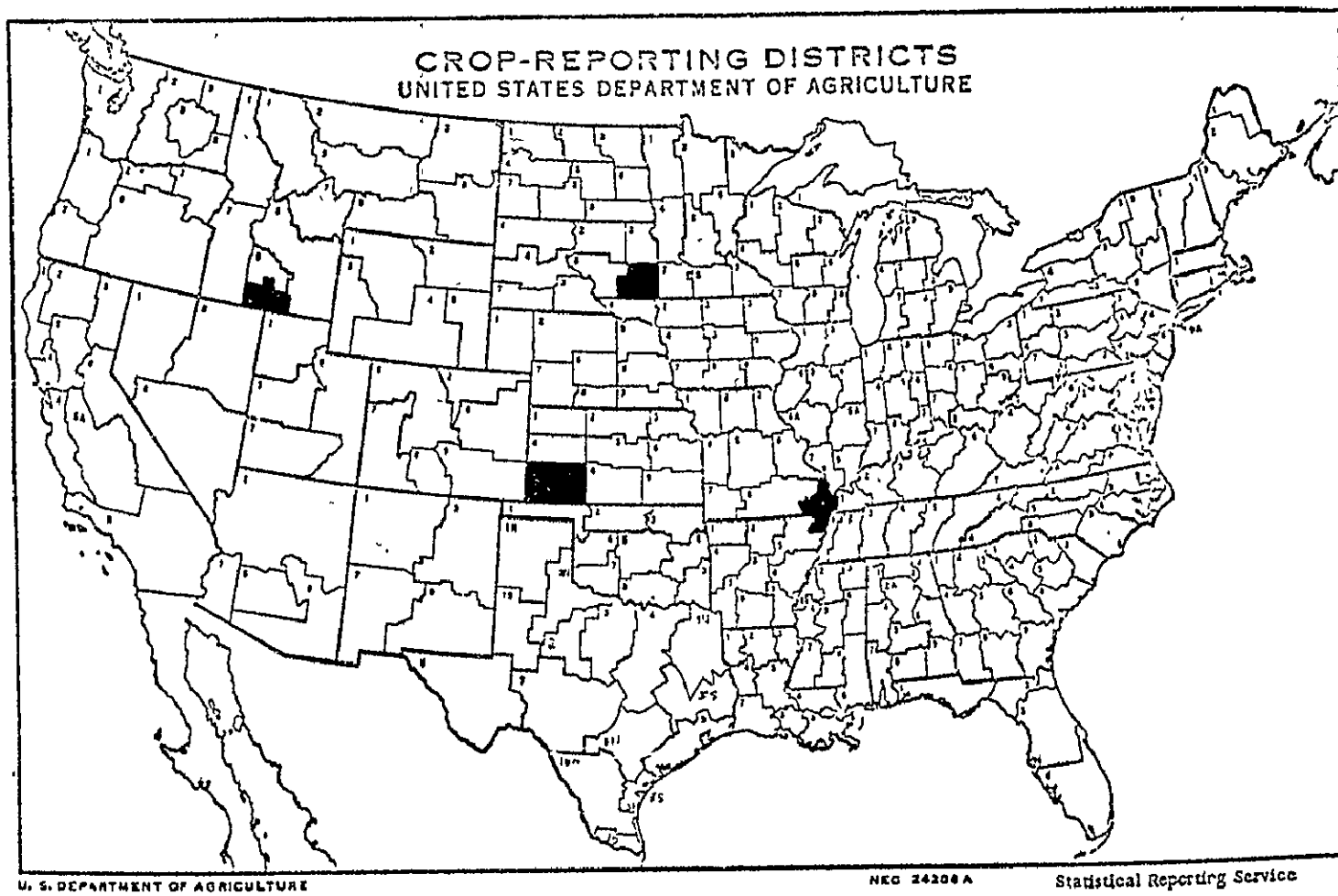


Figure J-19. Location of Von Steen Field Size Data

Table J-16. Field Size Distribution (Von Steen data) - South Dakota CRD 6

Crop	0-4.9 Acres				5-9.9 Acres				10-14.9 Acres				15-19.9 Acres				20-29.9 Acres				30+ Acres			
	Fields		Acres		Fields		Acres		Fields		Acres		Fields		Acres		Fields		Acres		Fields		Acres	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Farmland, etc.	33	10.5	19.8	10.5	49	45.5	137.6	39.4	14	13.0	157.0	18.4	6	5.6	93.0	10.9	3	2.7	62.0	7.3	3	2.7	115.0	13
Corn	5	2.9	11.9	0.2	12	6.9	92.7	1.4	15	8.6	179.0	2.7	16	9.2	279.8	4.1	42	26.1	301.3	15.5	94	45.4	115.0	13
Soy	7	5.9	22.0	0.6	10	8.4	71.1	2.0	10	8.4	111.0	3.1	12	10.1	205.1	5.5	30	25.2	67.1	13.3	50	47.0	111.0	13
Wheat	-	-	-	-	5	26.3	39.3	7.0	1	5.3	14.0	2.5	6	31.6	95.0	17.0	-	-	-	-	7	6.8	111.0	13
Winter Wheat	1	11.1	2.5	6.7	-	-	-	-	1	33.3	11.0	29.3	-	-	-	-	1	31.3	24.0	64.0	-	-	-	-
Summer Wheat	-	-	-	-	1	8.3	8.5	3.7	2	16.7	70.0	8.6	3	25.0	53.2	22.9	5	41.7	111.0	41.5	1	1	8.0	10
Barley	2	25.0	8.0	3.9	-	-	-	-	-	-	-	-	1	12.5	15.0	7.3	3	37.5	61.0	10.7	2	2	11.0	10
Oat	2	8.7	4.4	0.9	7	30.5	46.5	9.1	2	8.7	26.0	5.1	1	4.3	15.5	3.0	4	17.4	81.0	17.1	7	30.5	11.0	10
Alfalfa	6	6.5	19.2	0.9	9	9.9	61.2	2.8	20	22.0	211.2	10.7	13	14.3	211.0	9.6	23	25.3	519.0	23.7	20	27.0	11.0	10
Grass Hay	10	55.5	20.0	4.0	1	5.6	5.0	1.0	2	11.1	20.0	4.1	1	5.6	16.0	3.2	-	-	-	-	4	12.0	11.0	10
Flax	1	5.6	2.5	0.7	1	5.5	7.0	1.9	3	16.7	35.0	9.5	2	11.1	34.0	9.3	8	41.4	197.0	57.4	3	10.0	11.0	10
Pasture	4	6.8	16.5	0.3	4	4.6	75.5	0.5	12	13.6	128.0	2.8	3	3.4	46.0	1.0	9	10.2	27.0	6.8	74	11.5	11.0	10
Wooded Pasture	5	10.4	12.5	1.1	6	12.5	41.7	3.0	9	10.0	109.4	7.8	4	8.3	69.0	4.9	10	20.0	177.5	16.1	14	27.0	11.0	10
Hay Field	0	12.7	22.5	1.3	4	6.4	27.0	1.6	7	11.1	75.0	4.4	10	15.9	171.9	10.0	13	20.6	301.5	17.7	21	11.3	111.0	13
Other Crops	7	53.7	21.7	16.2	3	23.1	21.5	16.0	2	15.4	23.0	17.1	-	-	-	-	-	-	-	-	1	7.4	18.0	10
Soil Improvement Crops	-	-	-	-	1	8.3	8.0	2.8	1	8.3	13.0	4.5	3	25.0	49.0	16.8	5	41.7	172.0	61.9	2	16.7	9.0	10
Idle	6	23.1	16.2	3.5	2	7.7	16.8	3.6	3	11.5	33.0	7.1	4	15.4	65.0	14.1	6	23.1	132.2	29.3	5	19.2	19.0	10
Rye	-	-	-	-	1	11.1	5.0	2.6	1	11.1	11.0	5.6	2	22.2	31.0	15.9	3	33.4	77.0	39.5	2	22.2	71.0	10
Winter Wheat	1	16.7	1.3	0.9	1	16.6	8.0	5.7	1	16.7	10.0	7.1	-	-	-	-	-	-	-	-	3	50.0	122.0	10
Summer Wheat	-	-	-	-	1	50.0	6.0	22.2	-	-	-	-	-	-	-	-	1	50.0	21.0	77.8	-	-	-	-
Total	100				118				106				87				166				263			
Total Fields	274.0				630.0				1210.6				1440.5				383.6				1709.6			
Acres	11.7				13.7				12.3				10.1				19.3				32			
% of total	2.1				3.4				4.9				5.8				15.6				69			
Average Size of field-acres	2.74				7.03				11.42				15.56				23.27				60			

Average Size of all fields = 28.74 acres

Table J-17. Field Size Distribution (Von Steen data) - Kansas CRD 7

Crop	0-4.9 Acres				5-9.9 Acres				10-14.9 Acres				15-19.9 Acres				20-24.9 Acres				25+ Acres			
	Fields		Acres		Fields		Acres		Fields		Acres		Fields		Acres		Fields		Acres		Fields		Acres	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Barley, etc.	41	56.9	82.5	20.0	19	26.4	106.8	25.8	5	6.9	50.0	12.1	2	2.8	34.0	8.2	3	4.2	68.0	16.5	2	2.8	32.1	17.4
Corn	2	4.2	7.5	0.7	2	4.2	14.0	0.4	2	4.2	20.0	0.5	1	2.1	18.0	0.4	2	4.1	45.0	1.1	39	81.7	1,190.4	97.4
Wheat	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	100.0	40	100.0	-	-	-	-
Perley	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	100.0	15.0	100.0
Winter Wheat	5	2.5	11.8	0.1	4	2.0	27.2	0.2	1	0.5	12.0	0.1	5	2.6	81.7	0.5	23	11.6	560.8	3.4	160	81.3	15,747.8	95.7
Pro	-	-	-	-	-	-	-	-	1	100.0	10.0	100.0	-	-	-	-	-	-	-	-	-	-	-	-
Vegetables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	100.0	4.0	100.0
Corn - 25	1	1.5	2.0	0.1	1	1.5	9.0	0.1	1	1.5	14.0	0.2	5	7.4	81.0	1.1	3	4.5	73.0	1.0	56	83.6	7,134.1	97.5
Alfalfa	1	4.3	4.0	0.2	1	4.4	7.5	0.5	2	8.7	22.0	1.4	2	8.7	34.0	2.3	2	8.7	55.0	3.5	15	65.2	1,415.7	92.1
Other Hay	2	20.0	6.0	4.3	4	40.0	26.0	18.4	-	-	-	-	-	-	-	-	2	20.0	44.0	31.2	2	20.0	65.0	44.1
Sugar Beets	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	100.0	129.1	100.0
Pasture	-	-	-	-	3	2.6	24.0	0.1	8	6.9	91.9	0.3	3	2.6	49.4	0.2	5	4.3	129.5	0.4	97	13.6	31,111.6	99.0
Grassland Pasture	1	6.2	3.9	0.4	2	12.5	13.8	1.4	2	12.6	22.6	2.3	1	6.2	17.0	1.8	-	-	-	-	10	62.5	91.0	94.1
Summer Fallow	5	2.7	15.3	0.1	3	1.6	20.7	0.1	6	3.2	64.0	0.4	10	5.3	167.3	0.9	10	5.4	241.8	1.3	153	81.6	17,788.0	97.2
Other Crops	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	100.0	60.0	100.0
Soil Improvement Crops	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	100.0	515.0	100.0
Idle	-	-	-	-	1	25.0	6.0	6.3	-	-	-	-	1	25.0	18.0	19.6	-	-	-	-	2	50.0	68.0	73.9
Totals:																								
Number of fields	58				40				28				30				52				544			
Acres	133.0				235.0				306.3				502.3				1,257.1				79,210.6			
Number of fields % of total	7.7				5.3				3.7				4.0				6.9				72.4			
Acres % of total	0.2				0.3				0.4				0.6				1.5				97.0			
Average Size of field-acres	2.3				6.4				10.9				16.7				24.2				145.1			

Average Size of all fields = 100.31 acres

Table J-18. Field Size Distribution (Von Steen data) - Missouri CRD 9

Crop	0-4.9 Acres				5-9.9 Acres				10-14.9 Acres				15-19.9 Acres				20-29.9 Acres				30+ Acres			
	Fields		Acres		Fields		Acres		Fields		Acres		Fields		Acres		Fields		Acres		Fields		Acres	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Timothy, etc.	71	57.7	134.1	13.1	17	13.0	107.8	10.5	16	13.0	134.5	13.0	6	4.9	97.0	9.5	8	6.5	186.0	18.2	5	4.1	315.0	30.7
Cotton	18	14.1	59.7	5.8	21	16.4	139.0	13.4	18	14.0	211.0	20.2	22	17.2	368.5	35.8	16	12.5	174.0	16.8	33	25.8	1744.5	168.0
Corn	6	20.0	16.0	1.5	8	26.7	52.9	5.1	9	20.0	106.0	10.2	3	3.3	15.0	1.4	4	3.3	96.0	9.2	2	6.7	84.0	8.1
Oats	1	100	4.0	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Barley	2	100	7.0	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Winter Wheat	4	4.6	9.7	0.6	15	17.2	106.0	10.2	25	20.7	278.6	26.8	13	15.0	212.2	20.2	16	19.4	362.5	34.6	14	16.1	739.1	71.9
Hay	3	42.9	7.5	17.8	3	42.8	22.0	40.3	-	-	-	-	-	-	-	-	1	14.3	75.0	45.0	-	-	-	-
Watermelons	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Apples	30	16.3	71.2	1.7	30	16.3	204.5	4.9	28	15.2	328.3	7.9	20	10.9	334.4	8.0	32	17.4	75.9	18.2	44	23.9	247.0	17.3
Corn up	2	20.5	7.0	7.7	2	24.6	12.0	13.2	1	14.3	10.0	11.0	-	-	-	-	1	14.3	25.0	27.5	1	14.3	37.0	6.6
Alfalfa	-	-	-	-	1	100	8.0	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cotton Hay	2	60.7	7.0	31.6	-	-	-	-	-	-	-	-	1	33.3	15.0	68.2	-	-	-	-	-	-	-	-
Flower	1	21.1	9.0	3.1	4	27.8	27.0	6.3	-	-	-	-	-	-	-	-	1	7.7	24.0	0.3	3	34.4	229.0	70.3
Pasture	1	20.0	4.0	5.2	2	40.0	12.7	16.6	-	-	-	-	-	-	-	-	1	20.0	20.0	26.1	1	20.0	4.0	57.1
Cropland Pasture	10	28.6	56.3	4.4	11	17.5	73.2	5.8	5	7.9	58.5	4.6	7	11.1	113.3	8.9	11	17.4	248.4	19.5	11	17.5	752.0	56.8
Other Crops	3	42.8	11.0	12.4	1	14.3	6.0	6.7	1	14.3	10.0	11.2	-	-	-	-	-	-	-	-	2	28.6	62.0	69.7
Soil Improvement Crops	-	-	-	-	1	50.0	8.0	24.2	-	-	-	-	-	-	-	-	1	50.0	25.0	25.8	-	-	-	-
Idle	20	47.6	42.5	24.2	13	30.9	91.4	31.1	5	11.9	55.5	18.9	1	2.4	18.8	6.4	2	4.8	47.0	15.9	1	2.4	40.0	13.6
	17	75.8	50.6	7.2	19	28.8	120.2	17.1	17	25.7	196.7	28.0	5	7.6	87.8	12.5	5	7.6	102.0	14.5	3	4.5	146.0	20.7
Totals																								
Number of fields	201				148				125				76				99				123			
Acres	495.8				990.7				1439.1				1262.0				1302.8				6720.7			
Number of fields % of total	26.0				19.2				16.2				9.9				12.8				15.9			
Acres % of total	3.8				9.3				20.9				9.6				37.4				50.9			
Average Size of field-acres	2.47				6.69				11.51				16.61				23.26				54.64			

Average Size of all fields = 17.11 acres

Table J-19. Field Size Distribution (Von Steen data) - South Central Idaho

Crop	0-4.9 Acres				5-9.9 Acres				10-14.9 Acres				15-19.9 Acres				20-29.9 Acres				30 + Acres			
	Fields		Acres		Fields		Acres		Fields		Acres		Fields		Acres		Fields		Acres		Fields		Acres	
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%
Pasture, etc.	138	55.9	301.9	1.2	46	18.6	278.1	1.1	18	7.3	113.1	0.4	5	2.0	81.0	0.3	14	5.7	333.3	1.3	26	10.5	264.7	1.0
Corn	6	10.9	15.1	1.7	13	23.6	95.1	10.9	11	20.0	134.7	15.4	11	20.0	180.0	20.6	9	16.4	214.8	24.5	5	9.1	21.6	26.9
Rice	1	25.0	2.2	4.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Barley	6	7.6	13.8	0.5	9	11.4	70.3	2.3	10	12.7	116.9	3.7	15	19.0	253.7	9.1	11	13.9	257.1	8.2	28	35.4	2,414.1	77.3
Winter Wheat	-	-	-	-	11	29.7	78.7	5.0	8	21.6	91.5	5.9	1	2.7	17.0	1.1	4	10.8	89.7	5.7	13	35.2	1,254.3	42.3
Mixed Grain	10	21.3	37.3	5.2	16	34.0	115.3	18.6	9	19.2	113.7	18.3	3	6.4	50.5	8.1	4	8.5	93.0	15.0	5	10.6	214.2	34.8
Spring Wheat	5	17.2	19.2	4.4	8	27.6	51.7	11.0	8	27.6	91.9	21.1	3	10.3	53.5	12.3	1	3.5	22.0	3.0	4	13.8	199.0	45.4
Buckwheat	-	-	-	-	1	5.3	8.0	0.8	2	10.5	27.6	2.0	1	5.7	18.0	1.8	1	5.3	25.0	2.6	14	23.7	935.0	92.0
Sweet Corn	2	13.3	6.5	1.3	2	13.4	12.0	2.5	3	20.0	35.1	7.3	1	6.7	16.3	3.4	2	13.3	41.7	8.7	5	33.3	31.1	71.8
Legumes	1	100.0	1.0	100.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hay	17	7.4	31.1	1.4	30	72.7	221.7	10.1	37	78.0	434.2	19.9	20	15.1	320.1	14.7	20	15.2	467.5	21.5	15	11.4	101.3	30.2
Field Peas	3	20.0	9.9	4.2	-	-	-	-	4	26.7	49.0	20.4	4	26.7	70.5	21.3	3	20.0	72.0	72.0	1	6.7	14.0	14.2
Soybeans	1	100.0	4.0	100.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Alfalfa	40	15.3	132.2	2.6	68	26.0	432.0	9.4	52	19.8	621.5	12.4	34	13.0	565.5	11.3	30	11.4	729.3	14.6	38	14.5	2,441.2	47.7
Other Hay	-	-	-	-	3	60.0	21.9	31.1	-	-	-	-	1	20.0	15.6	22.1	-	-	-	-	1	20.0	13.0	40.8
Clover	-	-	-	-	2	100.0	14.8	100.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Straw	8	11.1	25.6	1.7	13	18.0	95.9	6.5	17	23.6	193.3	13.1	12	16.7	204.9	13.8	11	15.3	274.8	18.6	11	15.3	654.3	46.3
Apples	-	-	-	-	1	100.0	7.0	100.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fruit	70	30.8	170.4	0.1	47	20.7	299.7	0.1	19	8.4	228.1	0.1	14	6.2	223.4	0.1	17	7.5	397.7	0.1	60	26.4	455.0	1.6
Cropland Pasture	5	20.0	12.1	3.3	10	40.0	72.3	19.5	5	20.0	56.5	15.2	1	4.0	19.0	5.1	-	-	-	-	4	16.0	211.0	40.9
Summer fallow	5	12.0	10.7	0.9	8	20.5	53.4	2.9	2	5.1	20.3	2.6	2	5.1	31.0	1.7	7	18.0	177.5	9.8	15	39.5	1,509.6	83.1
Other Crops	-	-	-	-	-	-	-	-	-	-	-	-	1	100.0	17.0	100.0	-	-	-	-	-	-	-	-
Soil Improvement Crops	3	33.3	8.0	10.1	4	44.5	28.9	36.4	1	11.1	11.0	13.9	-	-	-	-	-	-	-	-	1	11.1	31.4	39.6
Idle Cropland	21	51.2	61.0	13.9	14	34.2	93.7	21.4	2	4.9	26.3	6.1	1	2.4	15.0	3.4	-	-	-	-	3	7.3	243.6	55.2
Totals:																								
Number of fields	335				306				208				133				133				248			
Acres	865.1				2,102.4				2,473.1				2,202.5				3,199.4				491,355.8			
Number of fields % of total	24.5				22.4				15.2				9.7				9.7				18.2			
Acres % of total	0.2				0.4				0.5				0.5				0.6				97.8			
Average size of field-acres	2.6				6.9				11.9				16.6				24.1				1,973.3			

Average Size of all fields = 367.91 acres



### J.3.3 OTHER FIELD SIZE DATA

Also reviewed were field size data for the following areas:

- 1) Williams County, North Dakota
- 2) Melfort, Saskatchewan
- 3) Lee County, Illinois: CITARS

The distributions for Williams County and Melfort are shown in Figures J-48 and J-52. Figures J-53 presents the distribution for Lee County.

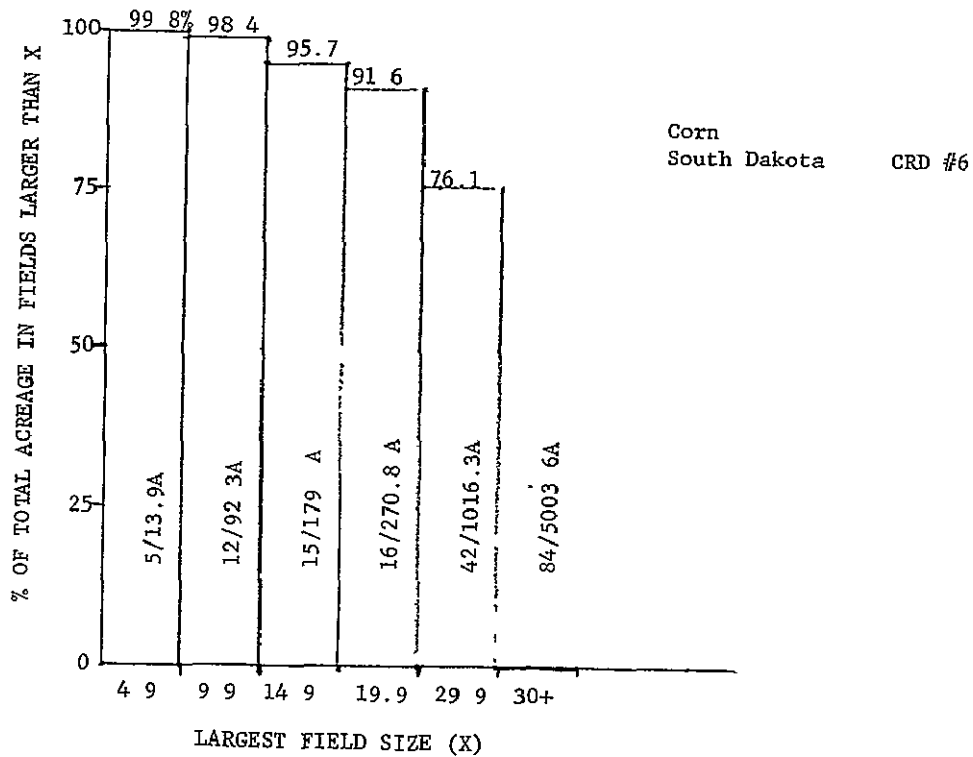


Figure J-20. Field Size Distribution (by Area) - Corn, South Dakota CRD No. 6

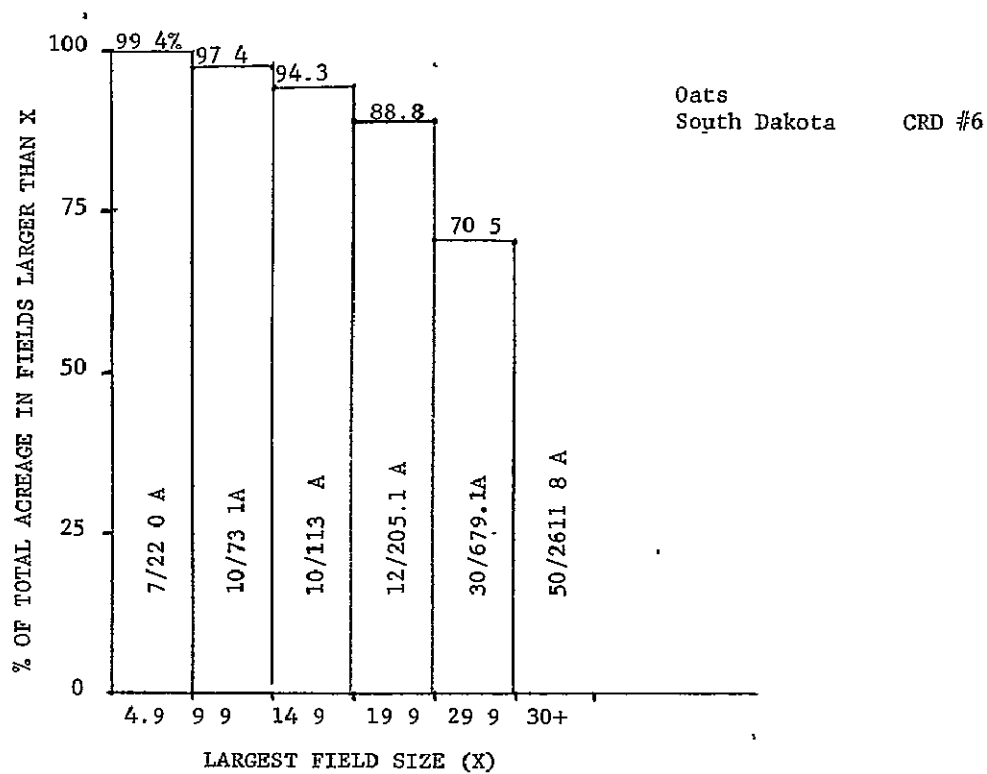


Figure J-21. Field Size Distribution (by Area) - Oats, South Dakota CRD No. 6

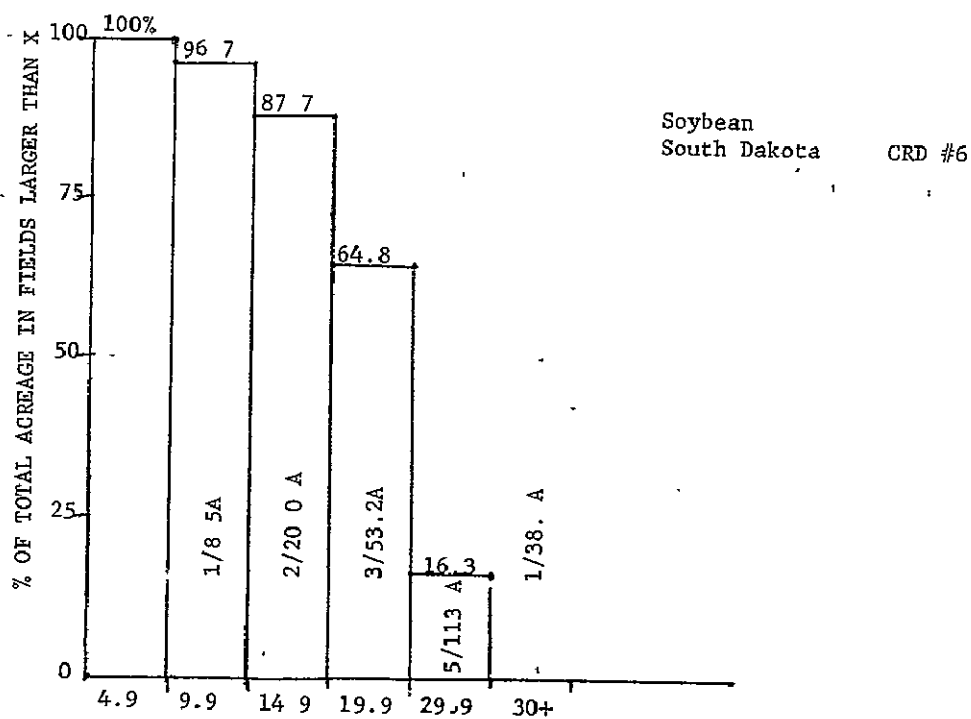


Figure J-22. Field Size Distribution (by Area) - Soybeans, South Dakota CRD No. 6

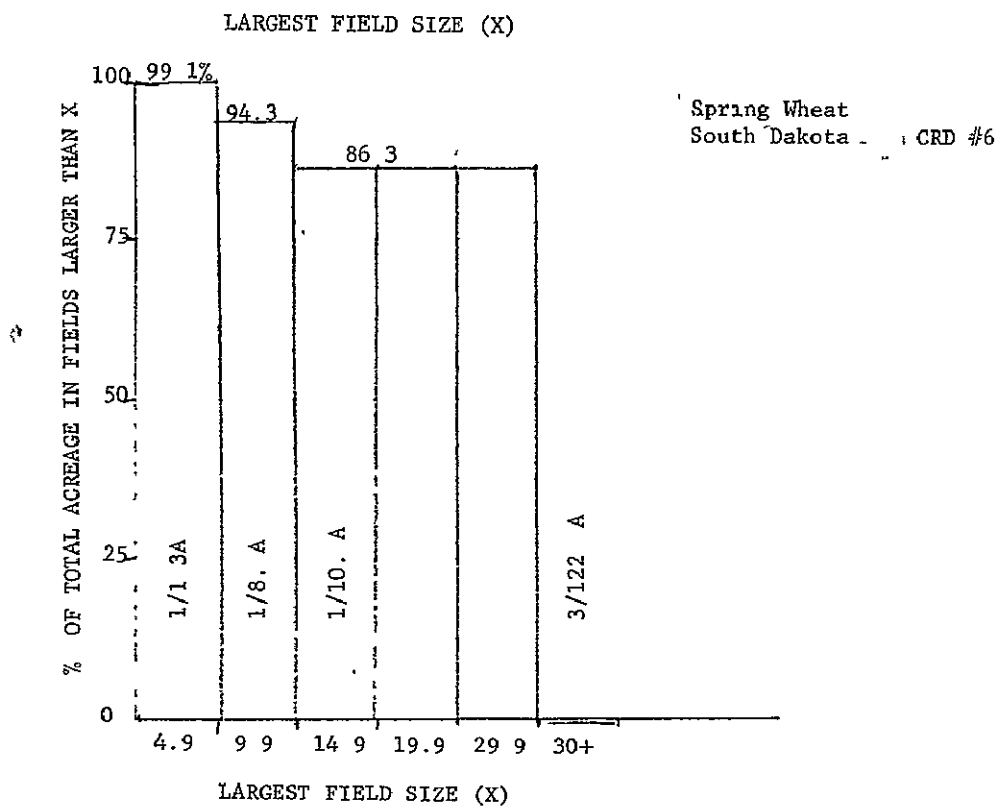


Figure J-23. Field Size Distribution (by Area) - Spring Wheat, CRD No. 6

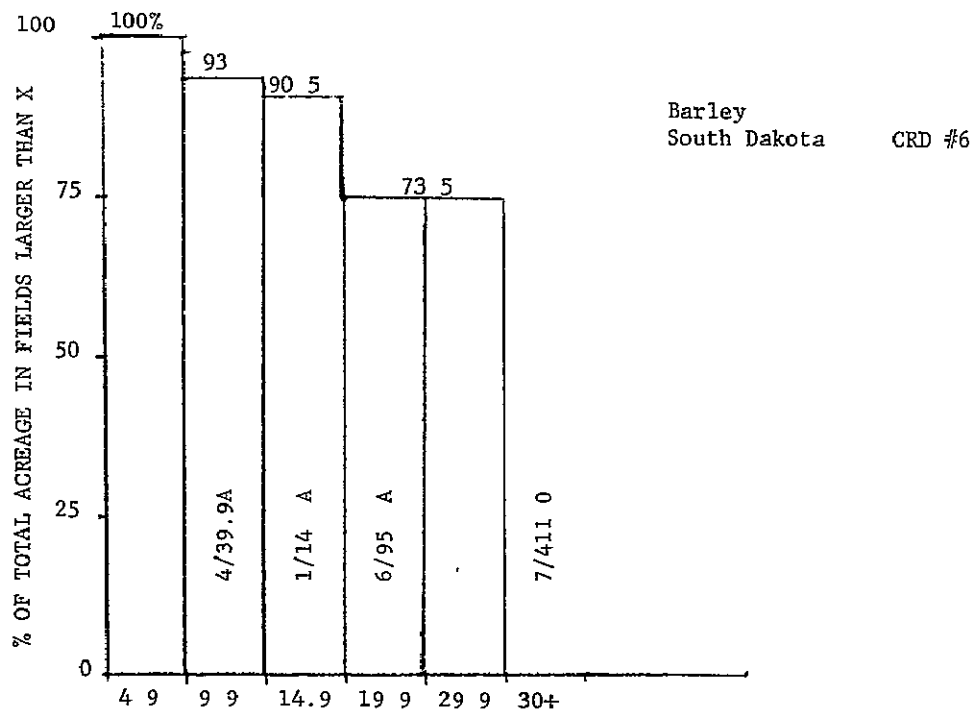


Figure J-24. Field Size Distribution (by Area) - Barley, CRD No. 6

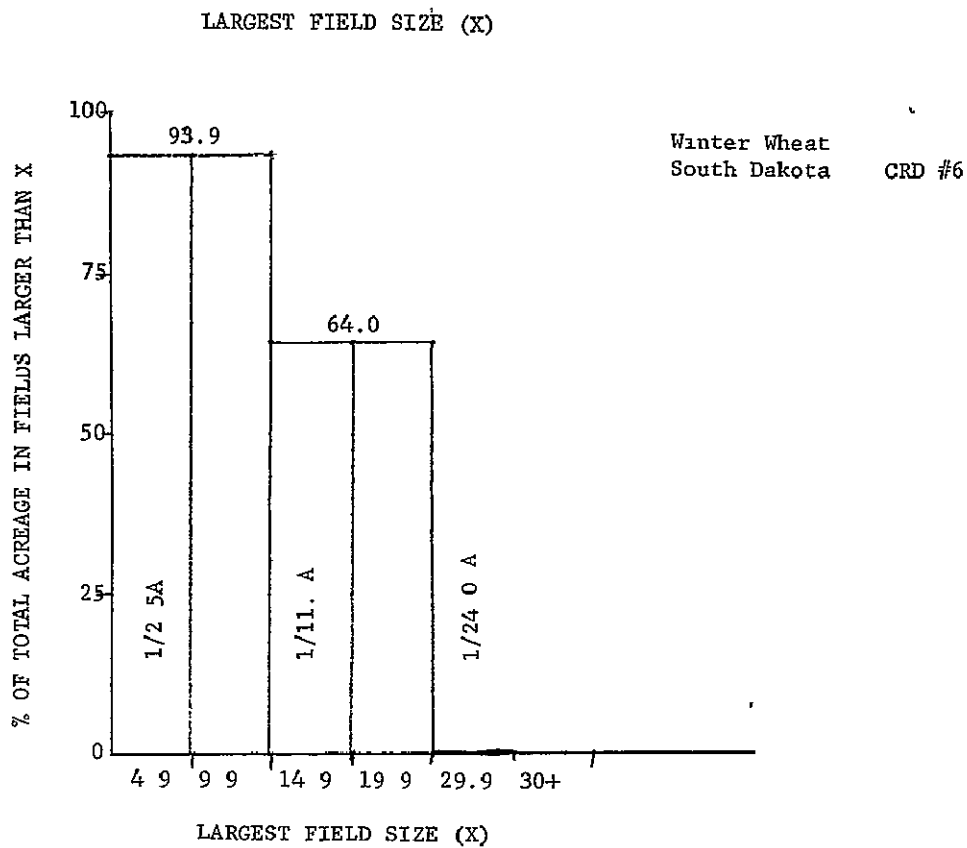


Figure J-25. Field Size Distribution (by Area) - Winter Wheat, CRD No. 6

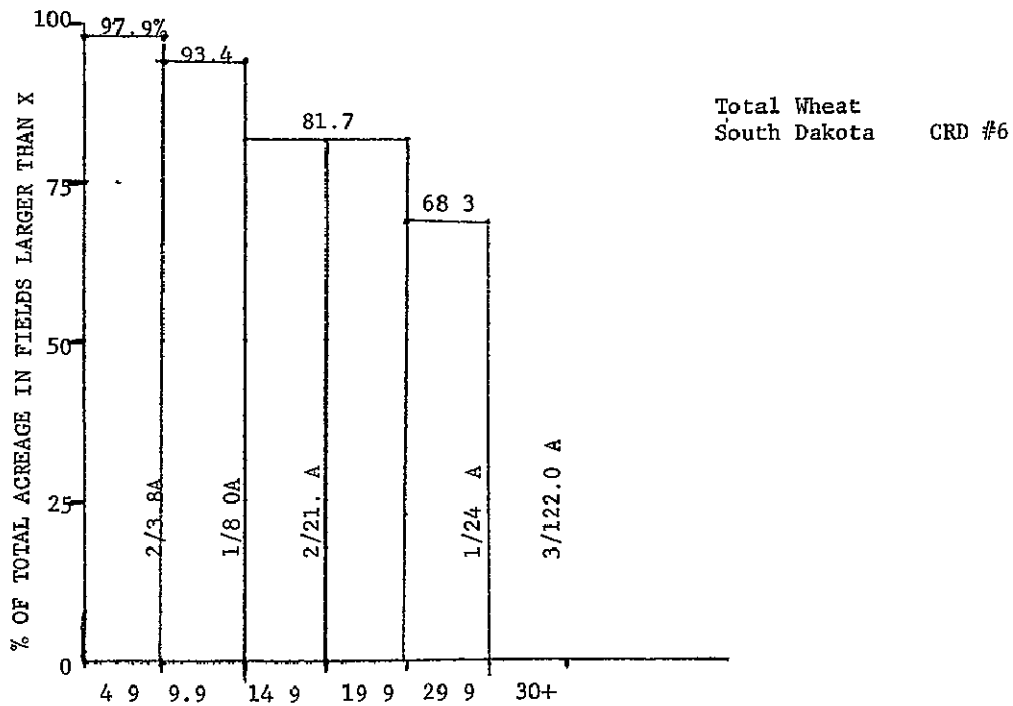


Figure J-26. Field Size Distribution (by Area) - Total Wheat, CRD No. 6

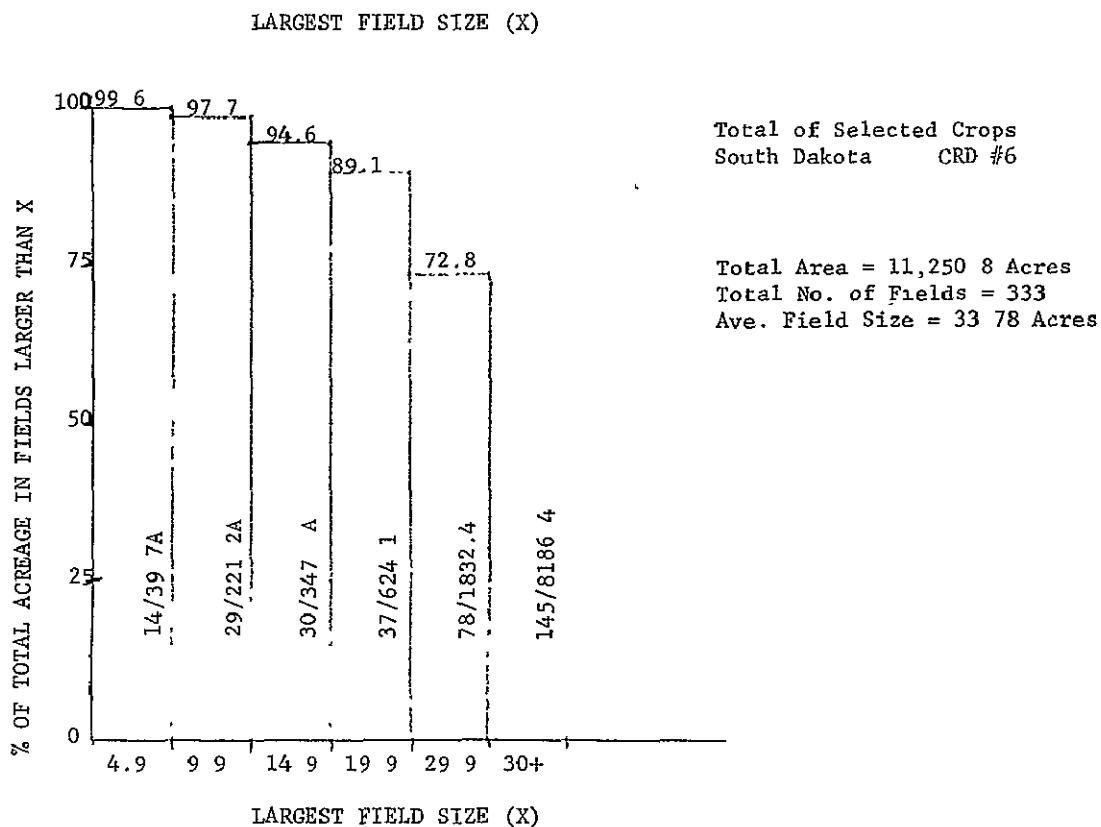


Figure J-27. Field Size Distribution (by Area) - Total Selected Crops, CRD No. 6

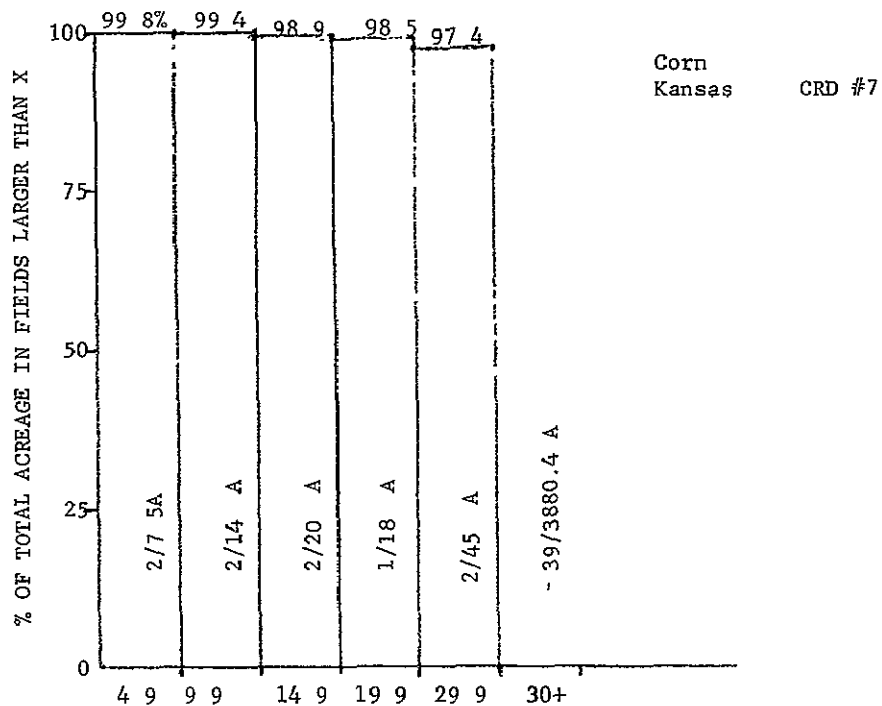


Figure J-28. Field Size Distribution (by Area) - Corn, Kansas CRD No. 7

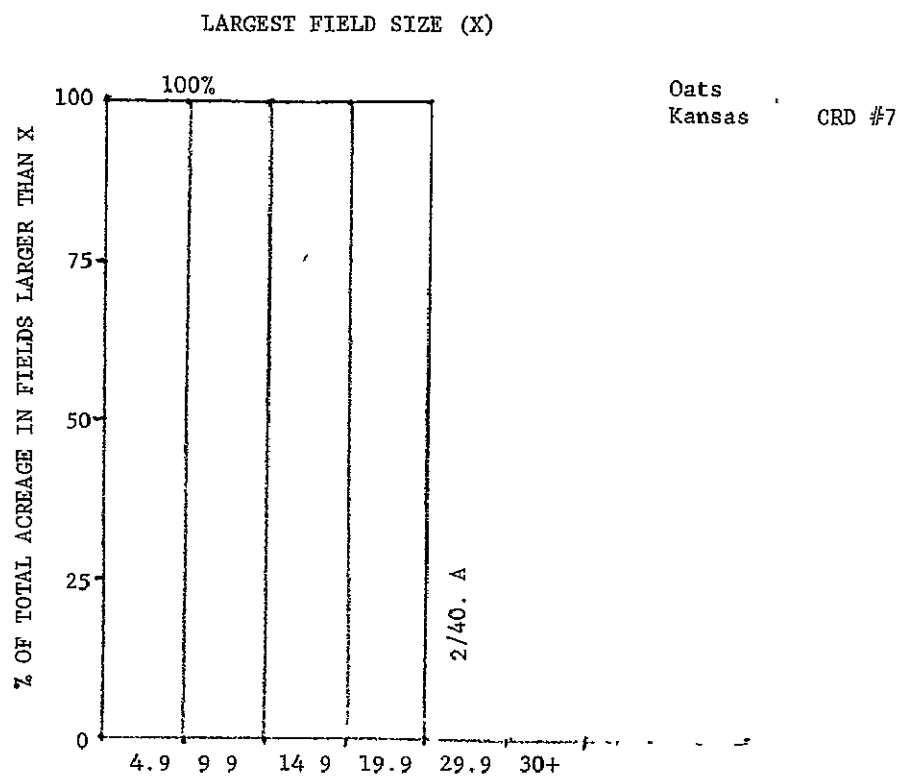


Figure J-29. Field Size Distribution (by Area) - Oats, CRD No. 7

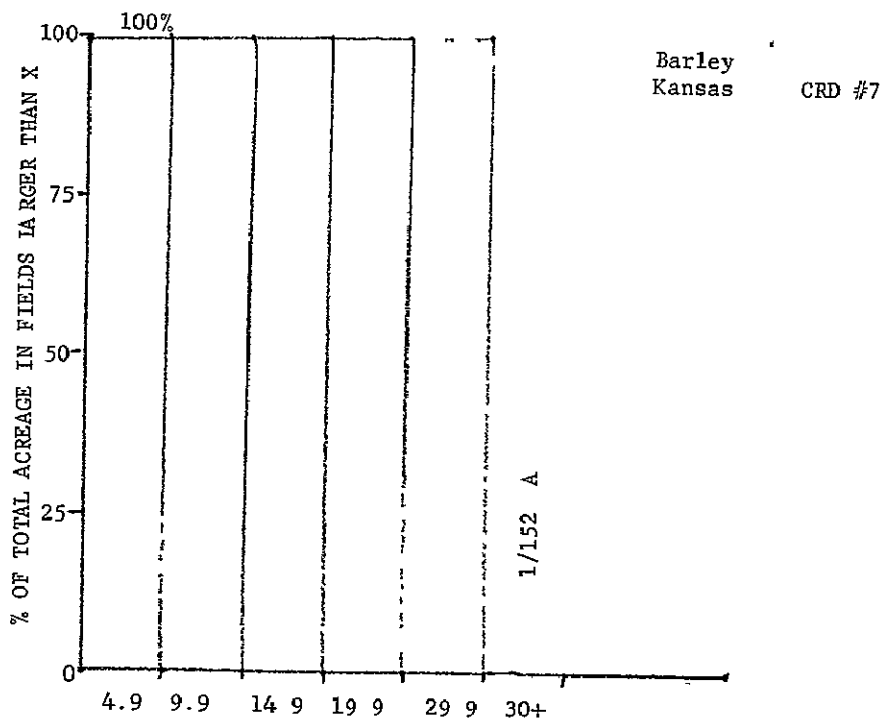


Figure J-30. Field Size Distribution (by Area) - Barley, CRD No. 7

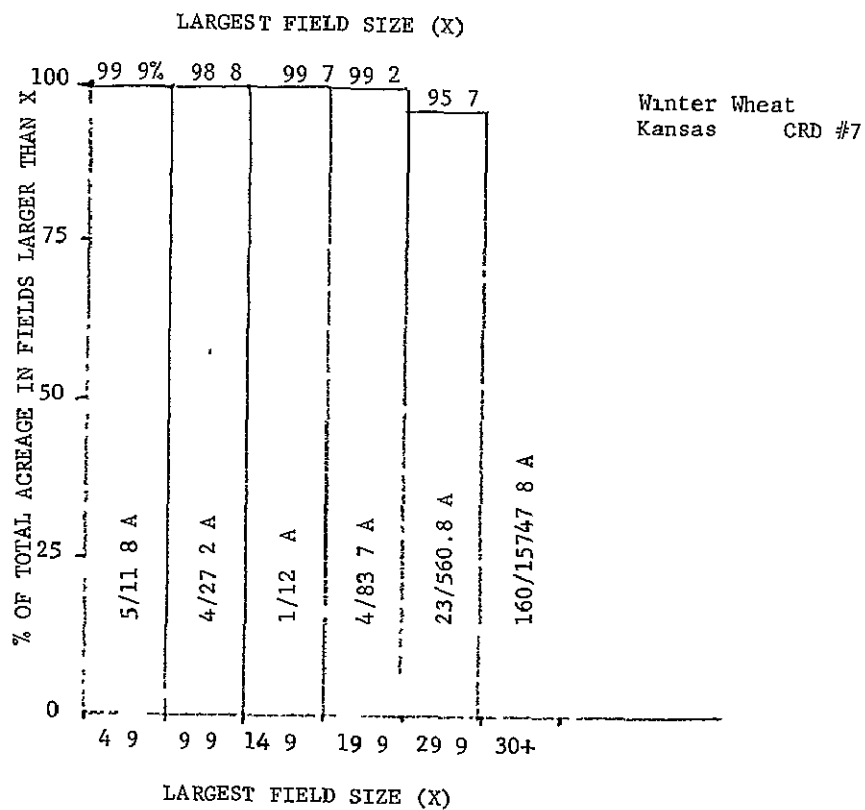


Figure J-31. Field Size Distribution (by Area) - Winter Wheat, CRD No. 7

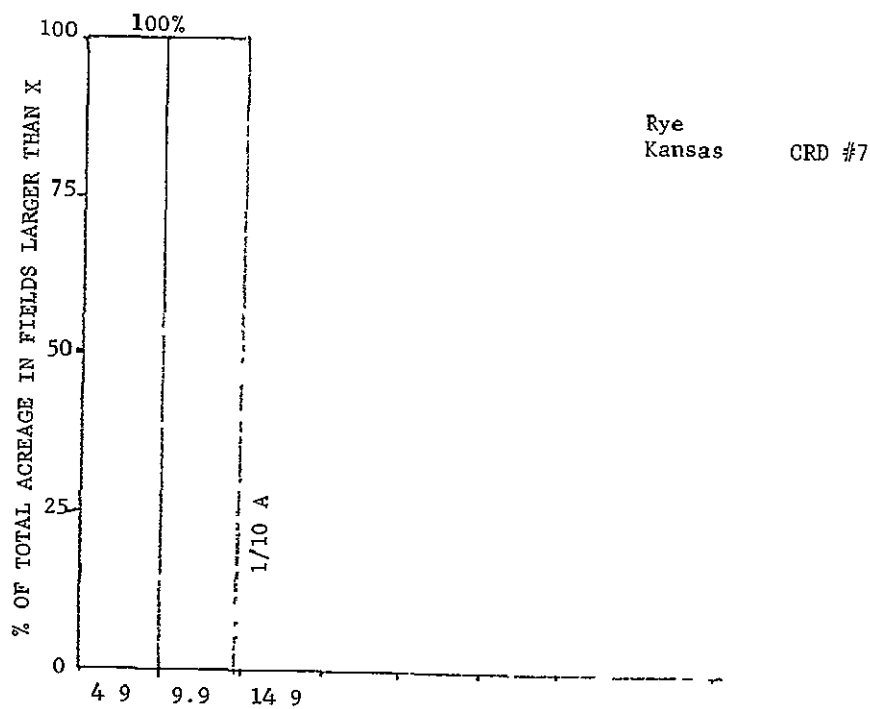


Figure J-32. Field Size Distribution (by Area) - Rye, CRD No. 7

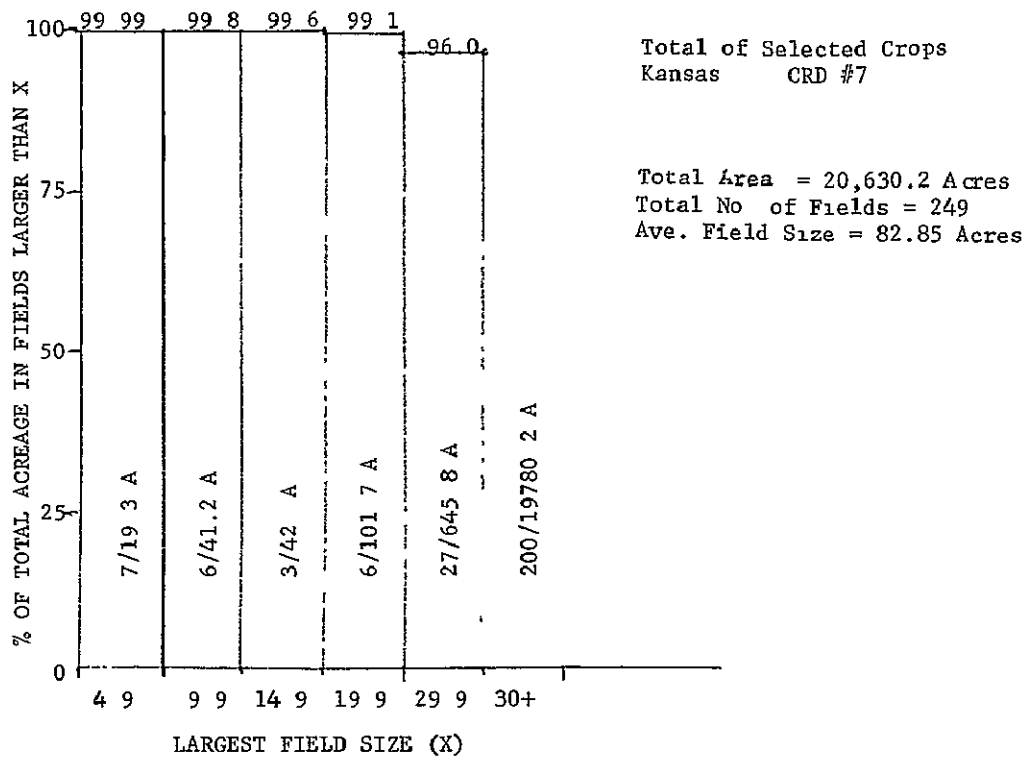


Figure J-33. Field Size Distribution (by Area) - Total Selected Crops, CRD No. 7

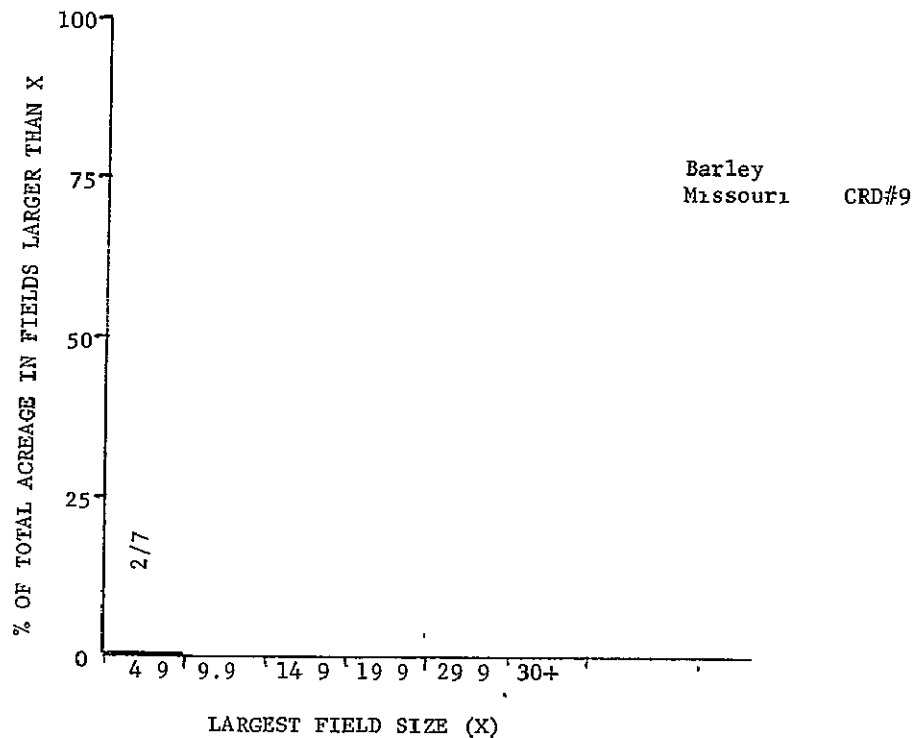


Figure J-34. Field Size Distribution (by Area) - Barley, Missouri, CRD No. 9



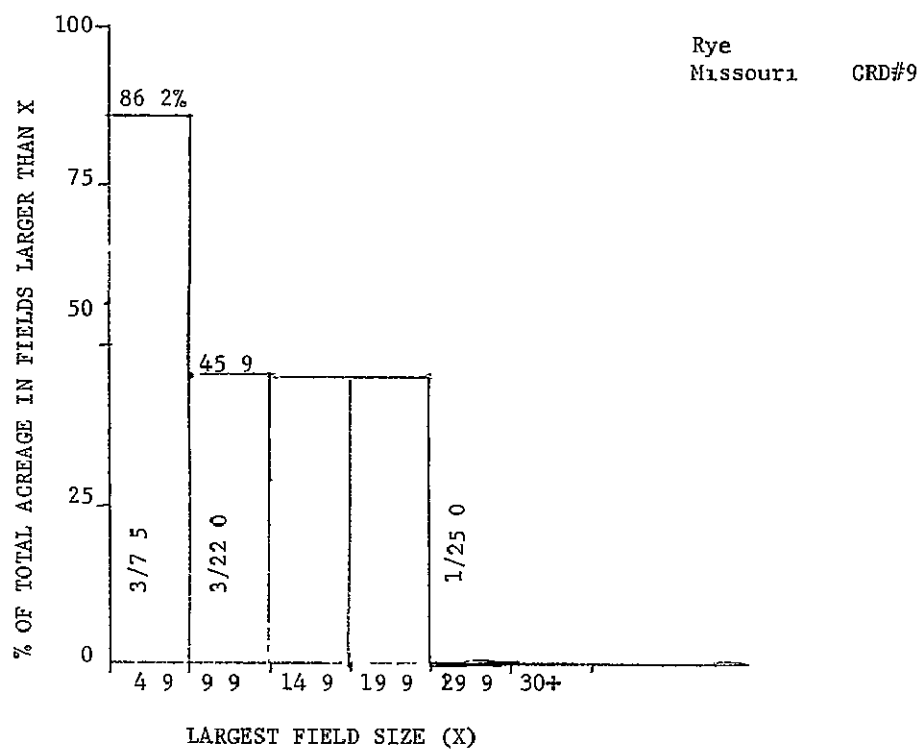


Figure J-35. Field Size Distribution (by Area) - Rye, CRD No. 9

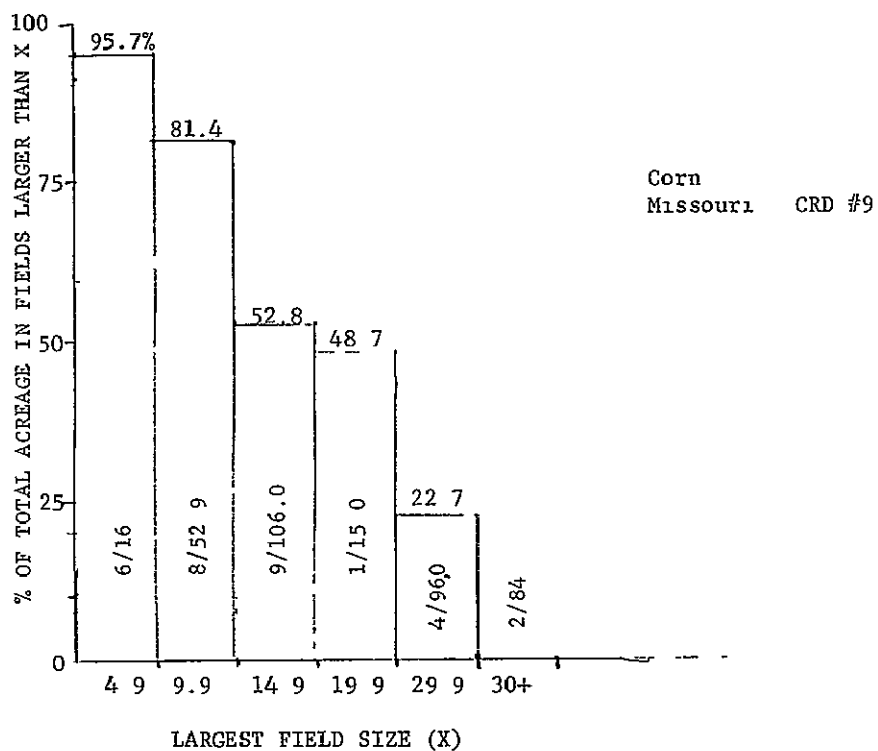


Figure J-36. Field Size Distribution (by Area) - Corn, CRD No. 9

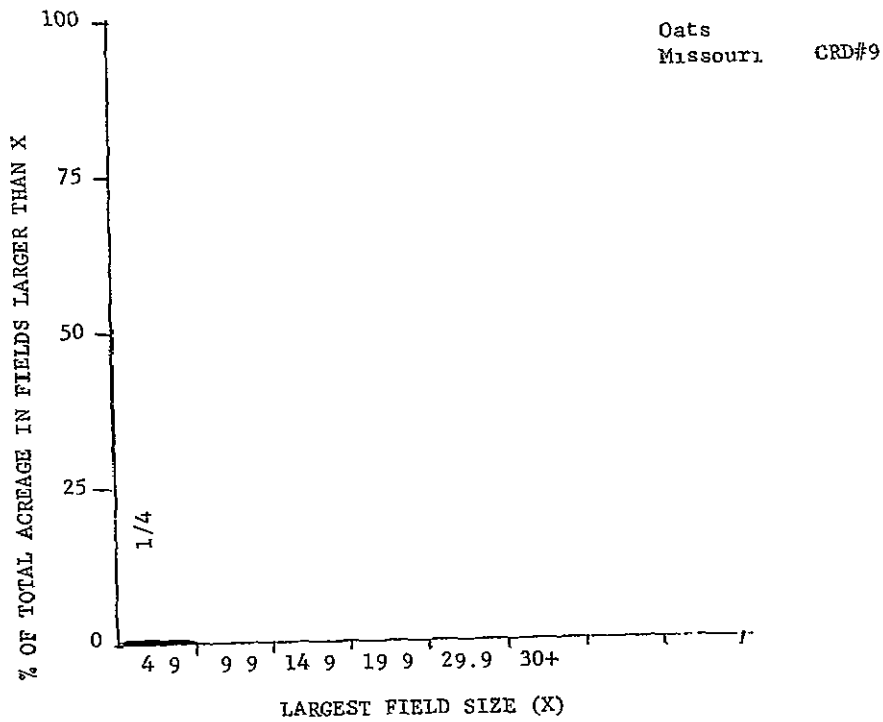


Figure J-37. Field Size Distribution (by Area) - Oats, Missouri, CRD No. 9

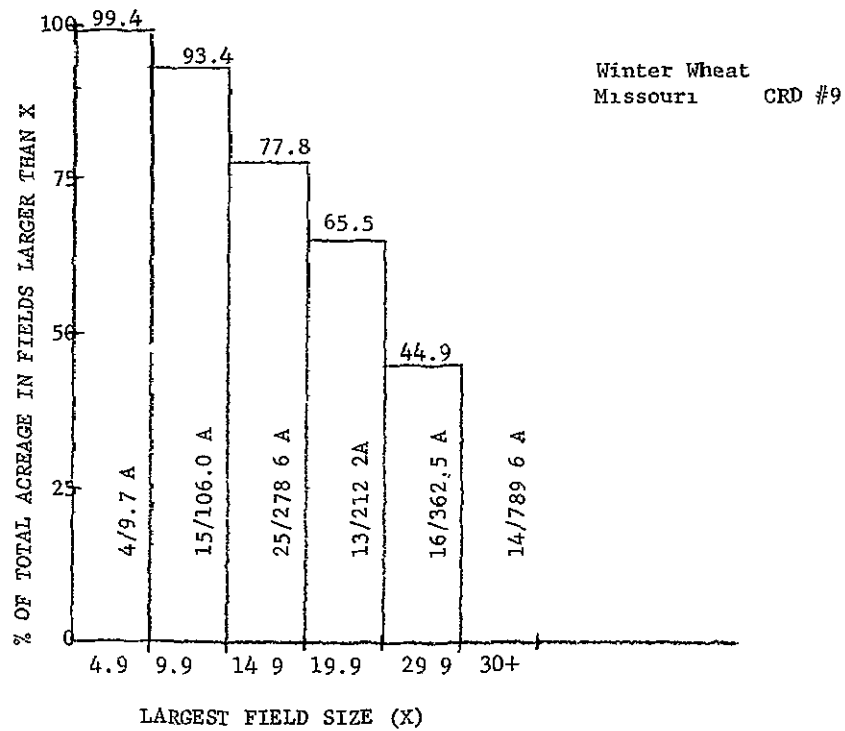


Figure J-38. Field Size Distribution (by Area) - Winter Wheat, Missouri, CRD No. 9

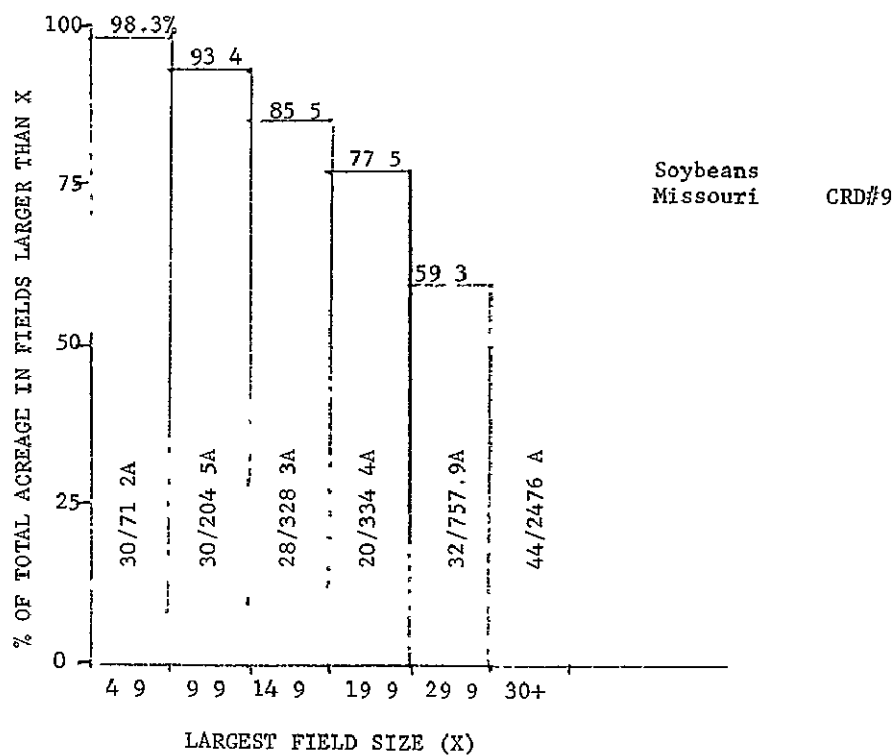


Figure J-39. Field Size Distribution (by Area) - Soybeans, Missouri, CRD No. 9

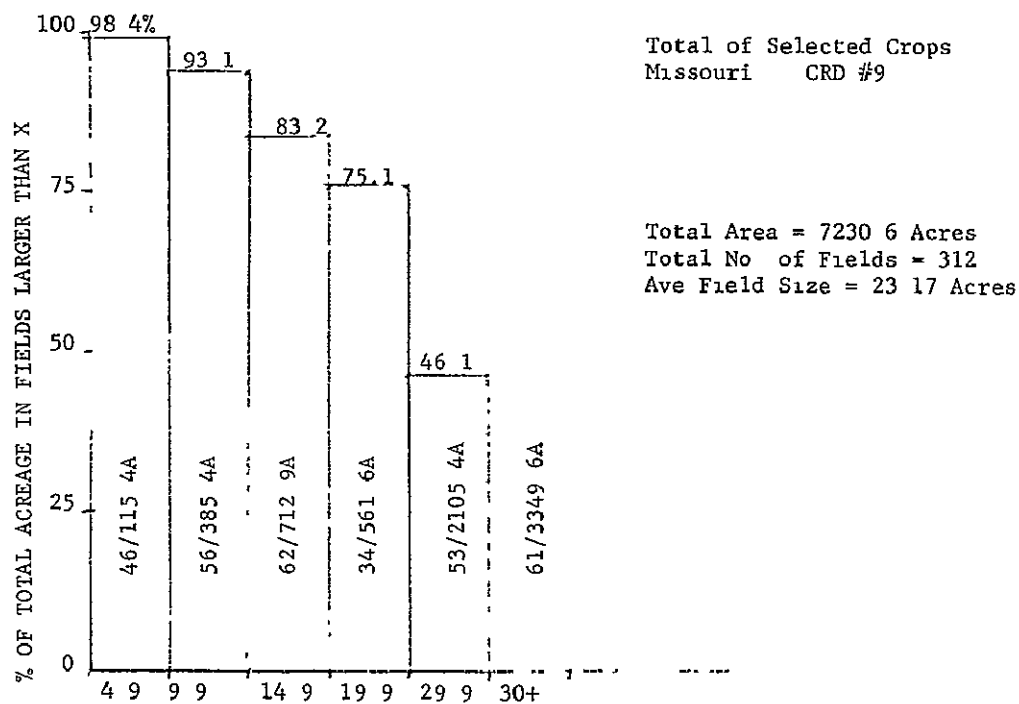


Figure J-40. Field Size Distribution (by Area) - Total Selected Crops, Missouri, CRD No. 9

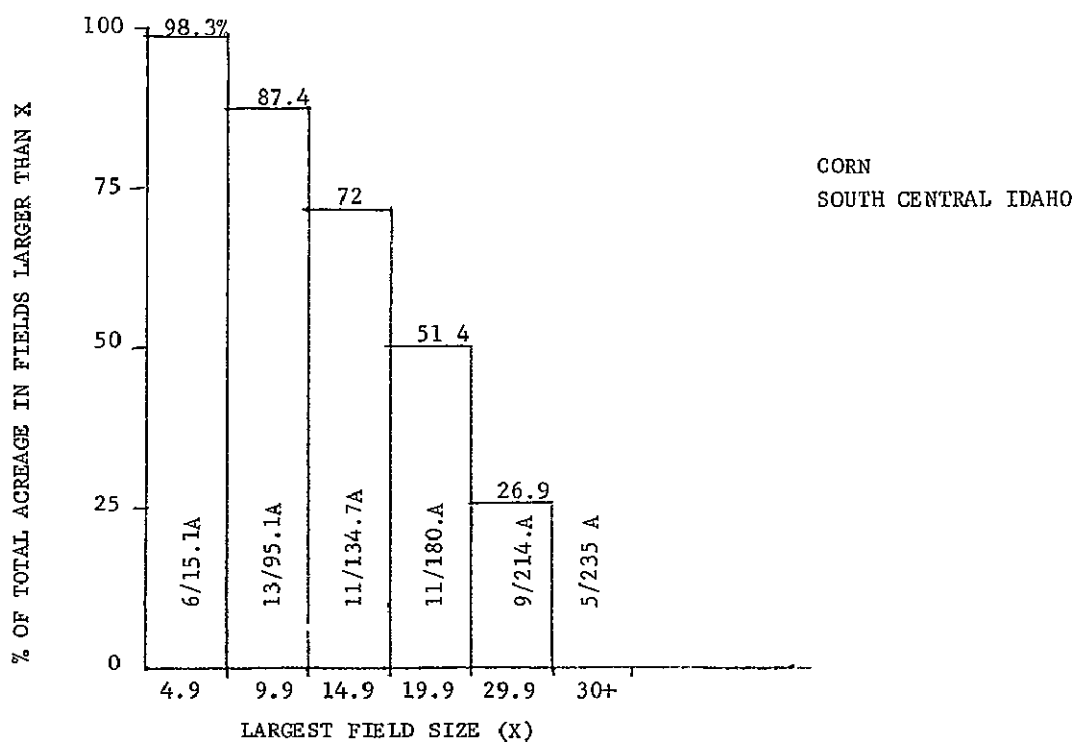


Figure J-41. Field Size Distribution (by Area) - Corn, South Central Idaho

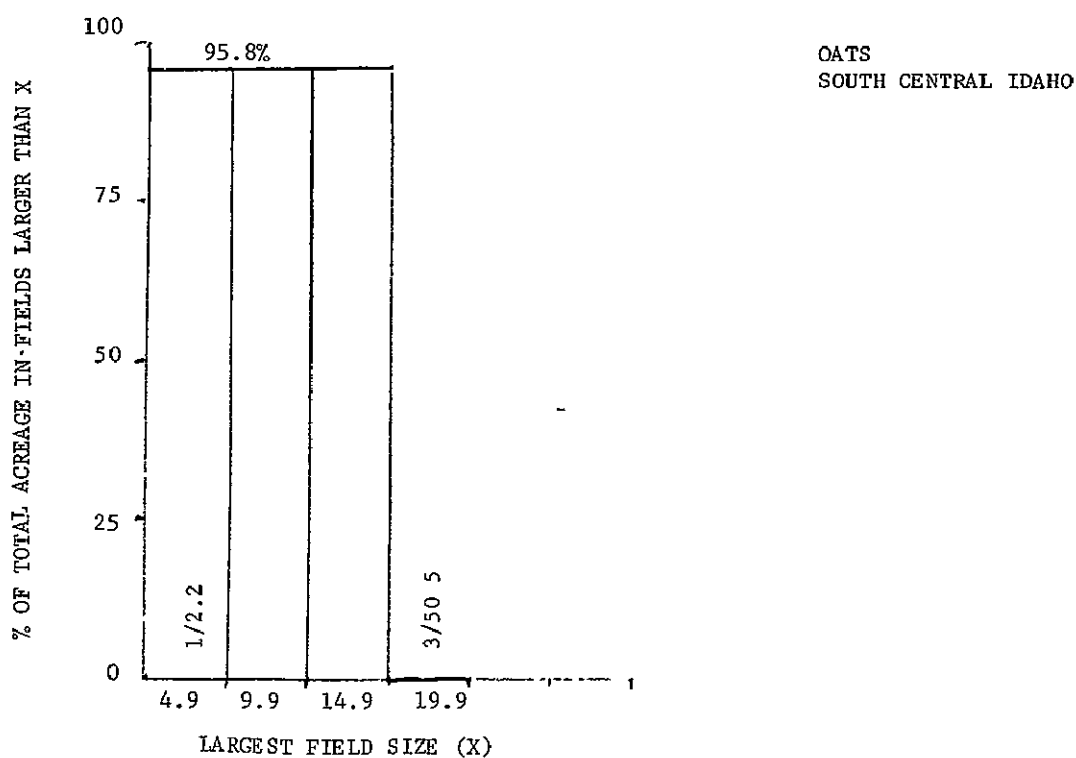


Figure J-42. Field Size Distribution (by Area) - Oats, South Central Idaho

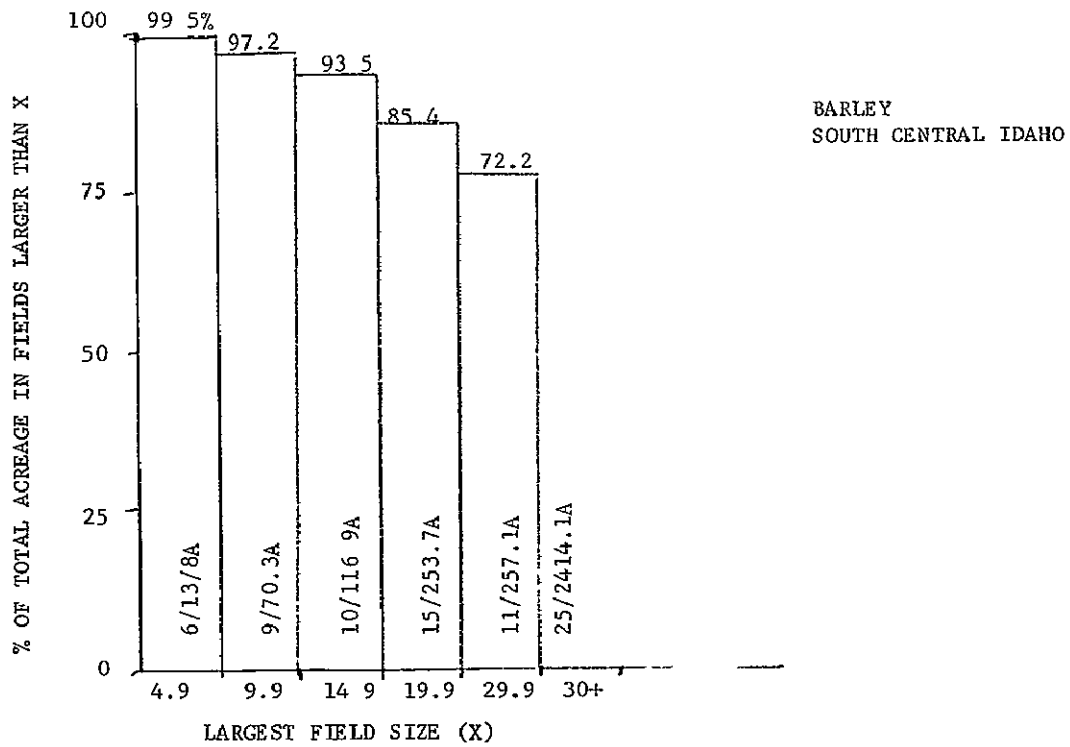


Figure J-43. Field Size Distribution (by Area) - Barley, South Central Idaho

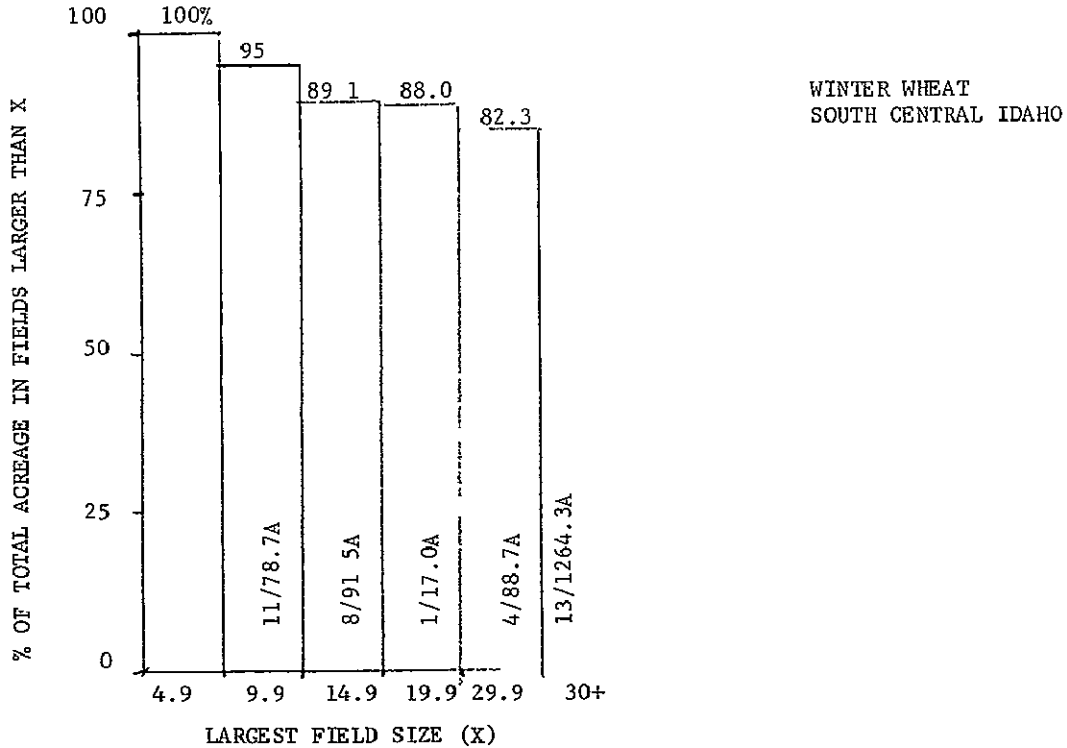


Figure J-44. Field Size Distribution (by Area) - Winter Wheat, South Central Idaho

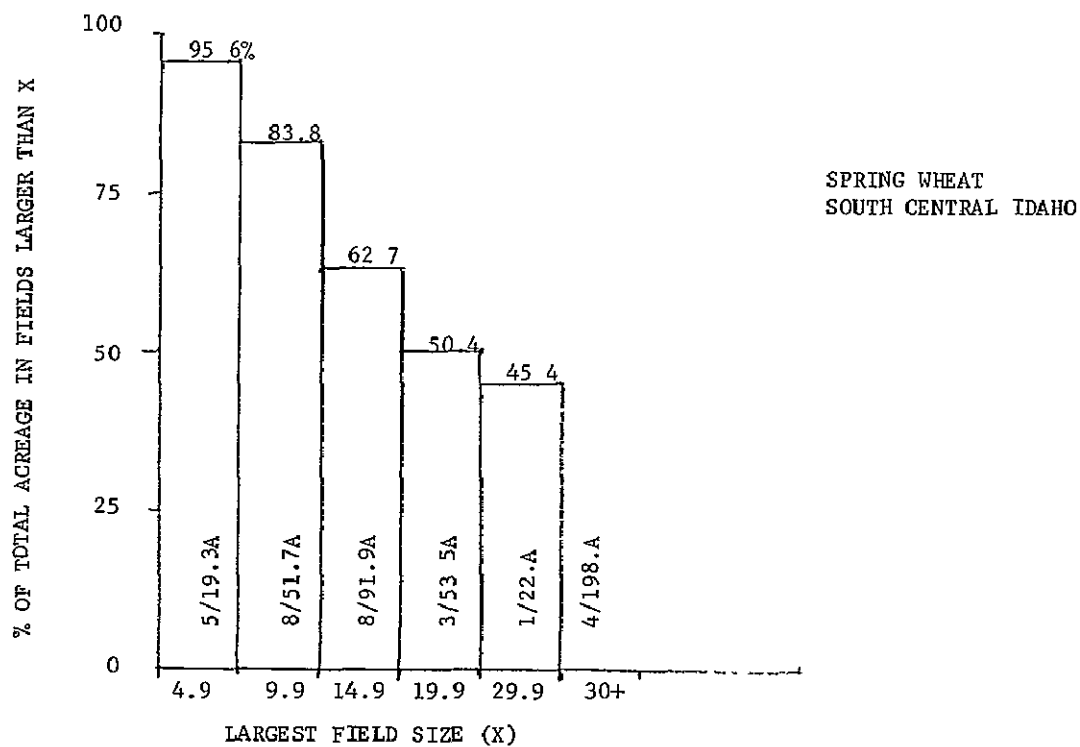


Figure J-45. Field Size Distribution (by Area) - Spring Wheat, South Central Idaho

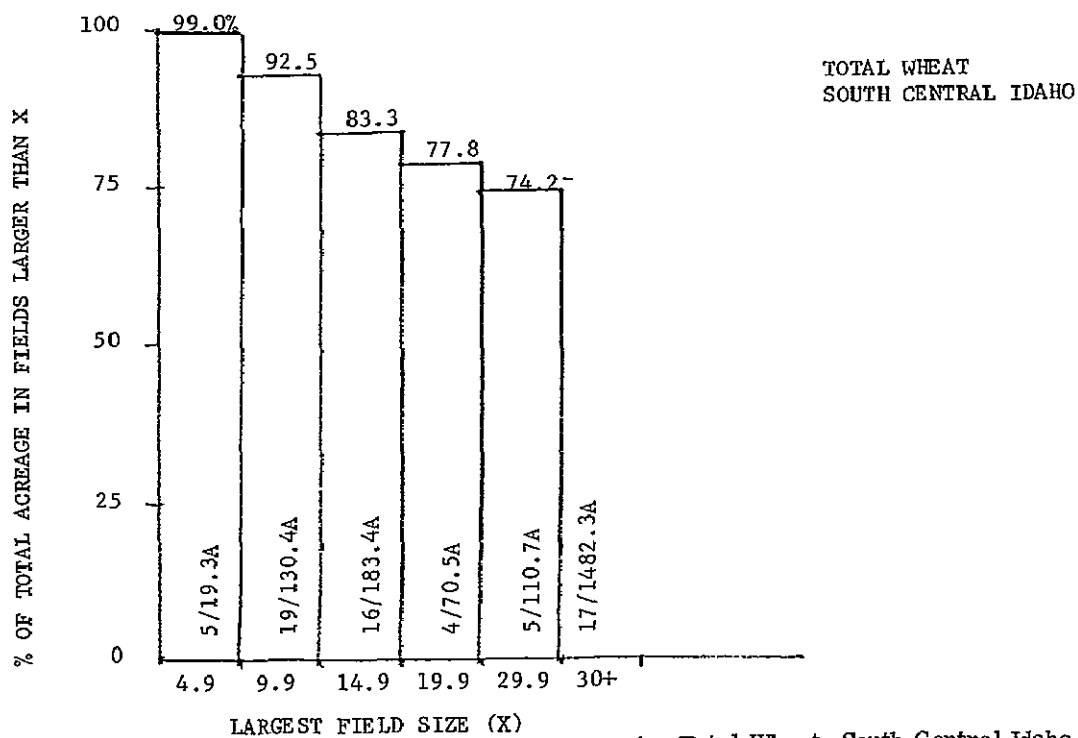


Figure J-46. Field Size Distribution (by Area) - Total Wheat, South Central Idaho

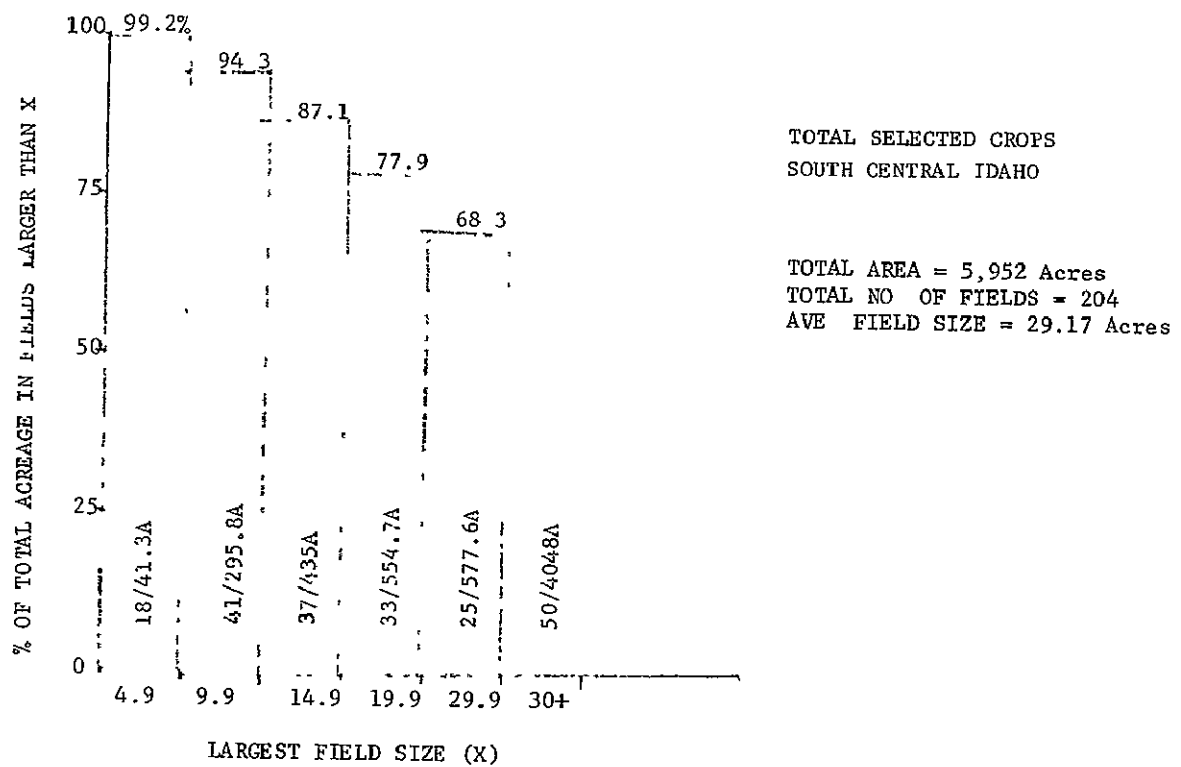


Figure J-47. Field Size Distribution (by Area) - Total Selected Crops, South Central Idaho

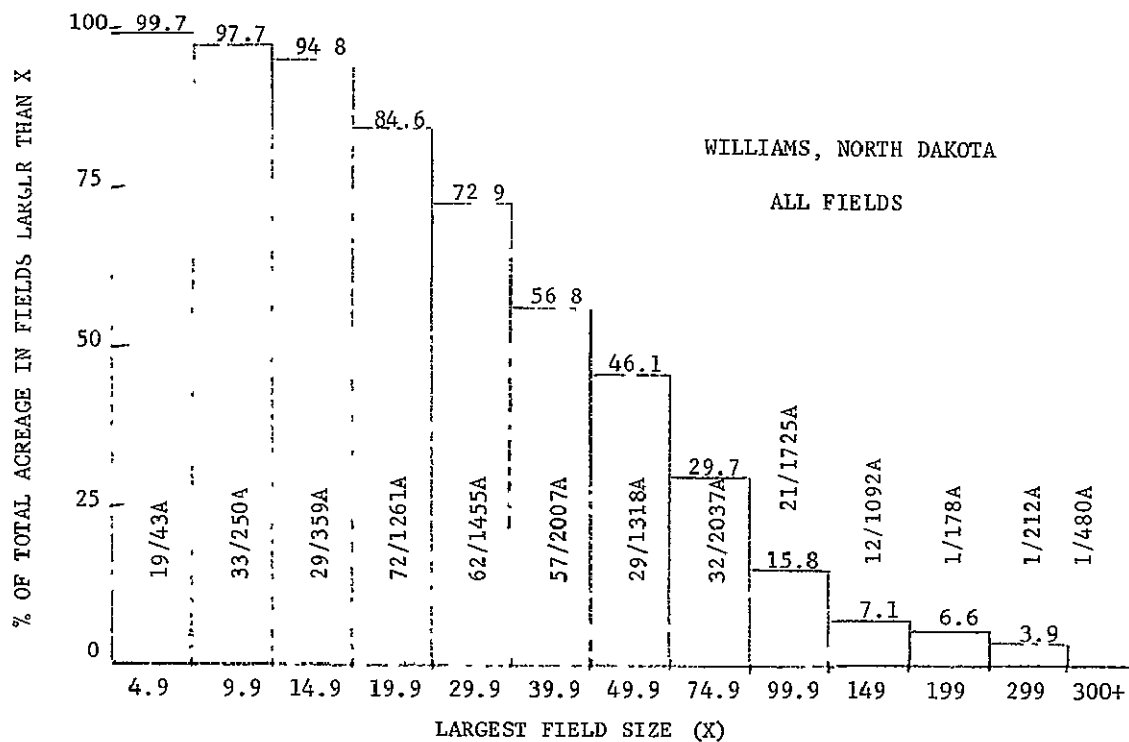


Figure J-48. Field Size Distribution (by Area) - All Fields, Williams, N. Dakota

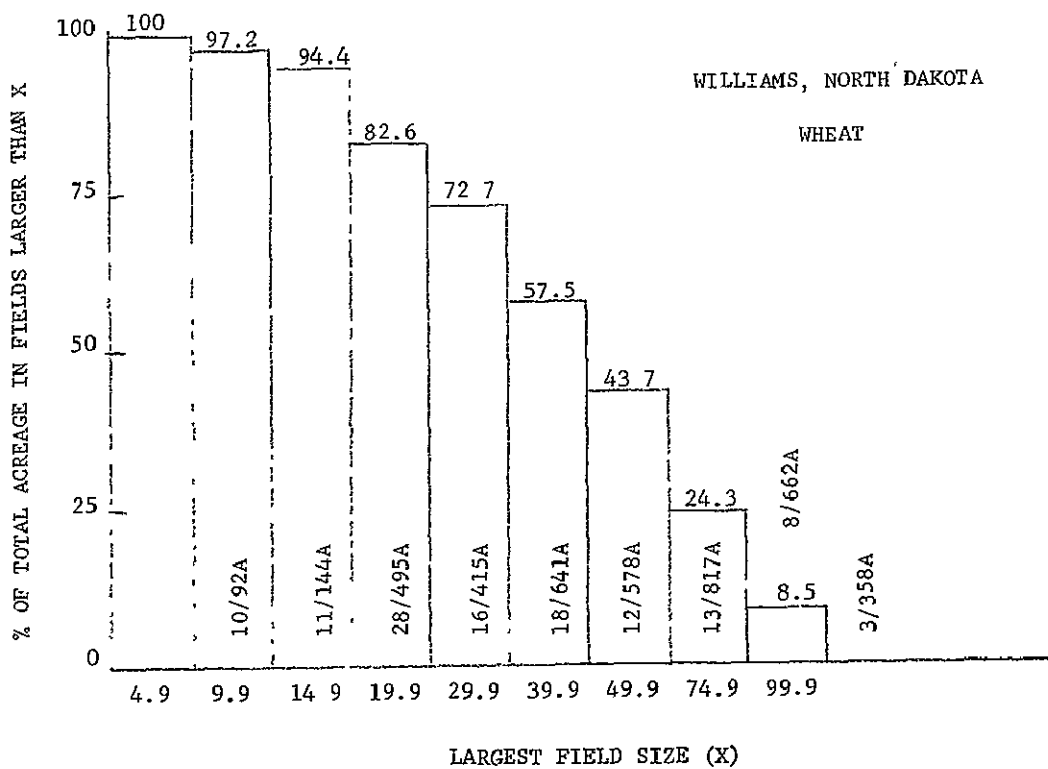


Figure J-49. Field Size Distribution (by Area) - Wheat, Williams, N. Dakota

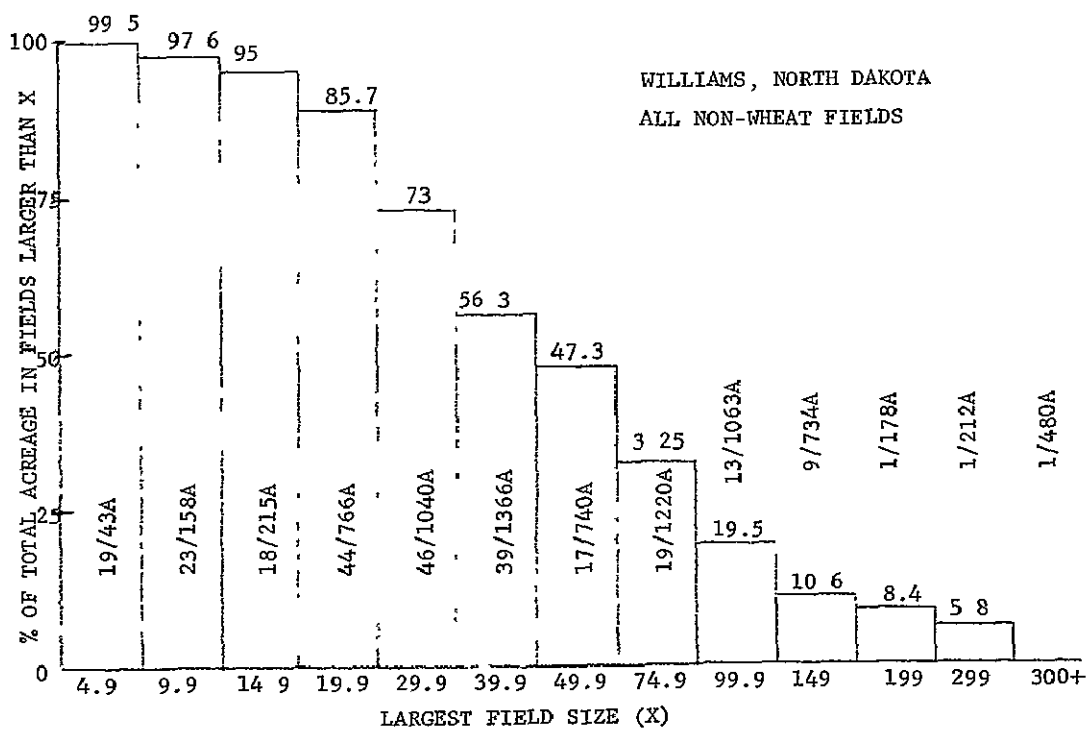


Figure J-50. Field Size Distribution (by Area) - All Non Wheat, Williams, N. Dakota



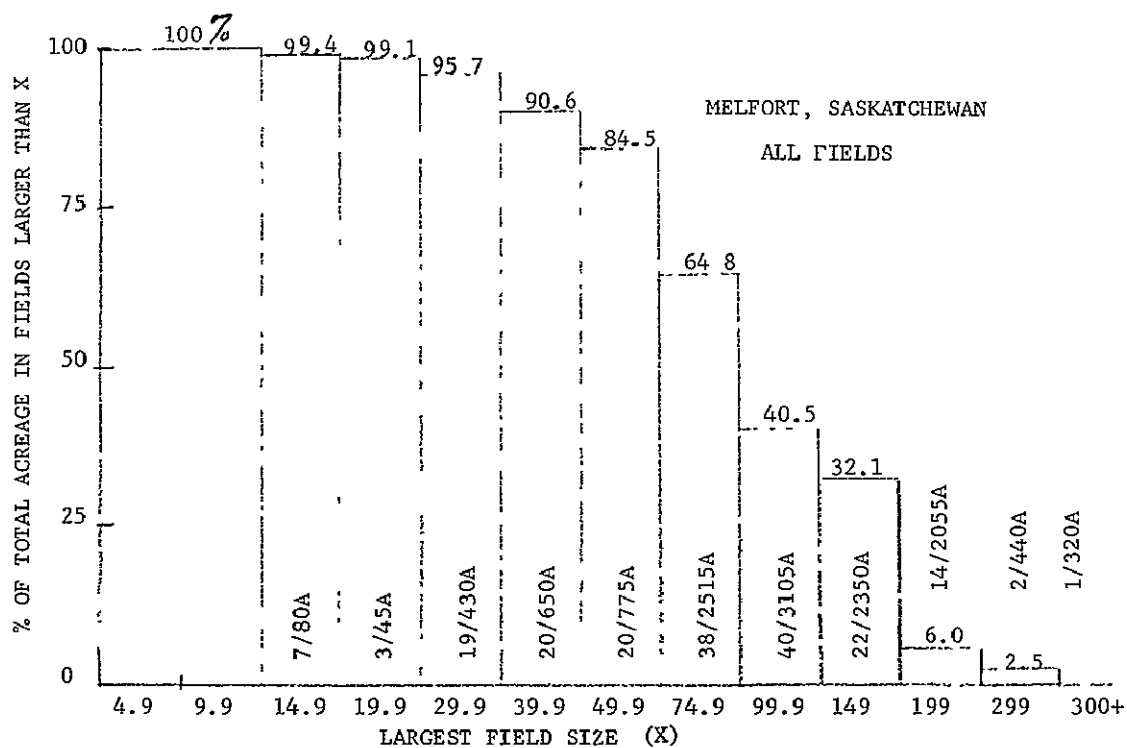


Figure J-51. Field Size Distribution (by Area) - All Fields, Melfort, Saskatchewan

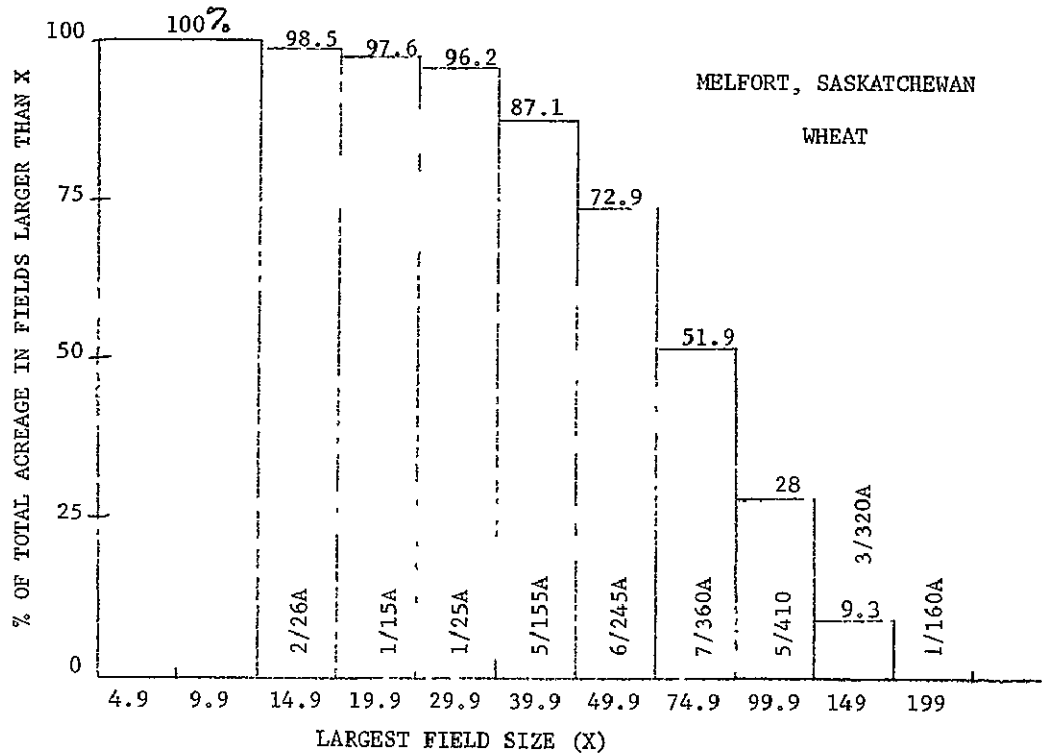


Figure J-52. Field Size Distribution (by Area) - Wheat, Melfort, Saskatchewan

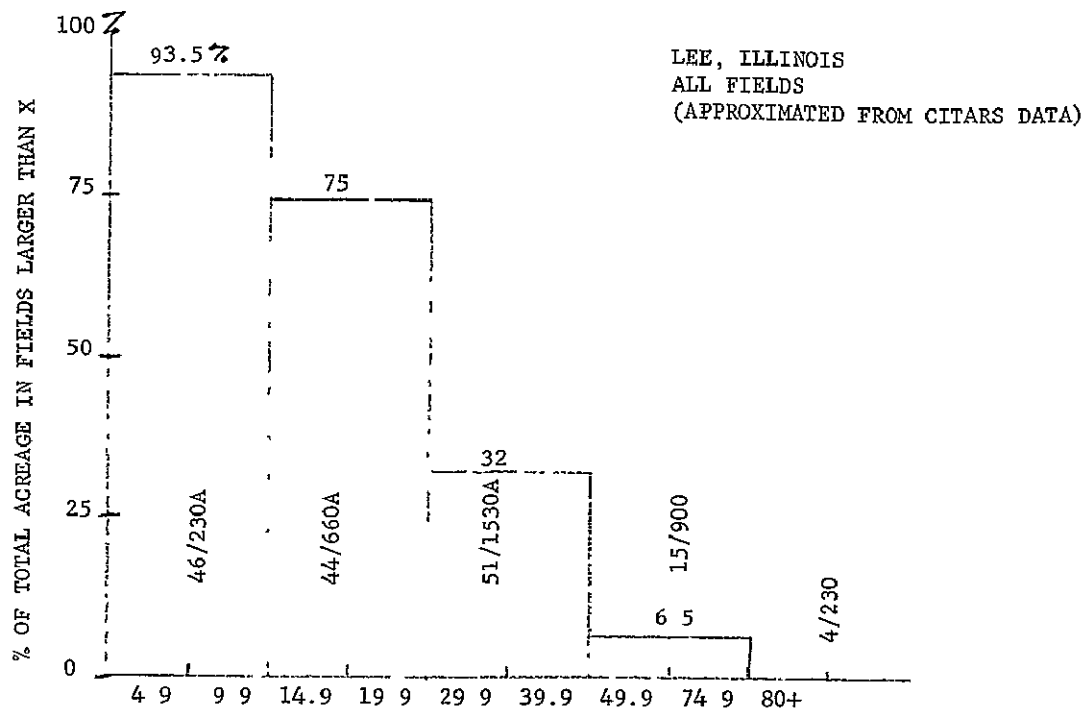


Figure J-53. Field Size Distribution (by Area) - All Fields, Lee County, Illinois

**APPENDIX K**  
**ANALYSIS OF CLOUD COVER**

APPENDIX K  
ANALYSIS OF CLOUD COVER

This appendix describes the derivation and results of the Cloud Cover analysis done for TOSS.

The overall conclusion (inference) that was drawn in this Appendix was that. there is approximately a one sigma confidence in achieving at least 40% of the attempted samples with a two pass per month (1 Spacecraft) system.

This conclusion is of course too broad and general to apply in all cases; nevertheless it is the approximation made for the TOSS study. A closer look at the impact of cloud cover could (and should) be done which will take explicitly into account the different cloud distribution statistics for each wheat growing area during each month of the growing season.

A simple cloud cover impact model appropriate to agricultural missions planning is developed here. The development is facilitated by the step-by-step solution of a hierarchy of "little problems".

K.1 PERFECT-RESOLUTION (POINT) SEEING PROBABILITY. The probability of seeing a point on the ground given only that there is a cloud cover amount  $c$  is

$$p(\text{seeing}/c) = 1 - c;$$

that is, the probability of seeing is just the total fraction of cloud-free area relative to the whole viewing area. In this model it is only assumed that the cloud cover consists of a distribution of discrete cloud elements randomly distributed across the field of view; or, equivalently, that the point target is randomly placed in the field-of-view. Cloud shadows and haze are ignored. The point seeing probability can be used when an imaging system's resolution is greater than the smallest cloud elements. The smallest cloud elements are the fair weather cumuli (the "popcorn" clouds seen on high-altitude photographs) with diameters of some 200 feet to 1 mile (Reference 1). Thus, for a probability of seeing analysis, an imaging system with a resolution of 30-50 m can be considered to have perfect resolution.

The total a priori probability-of-seeing (for all possible cloud cover amounts) is (by the laws of conditional probabilities):

$$\begin{aligned} p(\text{seeing}) &= \sum_c p(\text{seeing}/c) p(c) \\ &= \sum_c (1-c) p(c); \text{ or} \\ p(\text{seeing}) &= 1 - \bar{c}. \end{aligned}$$

$p(c)$  is the probability of occurrence of the cloud cover amount  $c$ , and  $\bar{c}$  is the mean cloud cover (for a particular month, time-of-day, and place). It should be noted that the mean cloud cover does not depend on the field-of-view or

observing area as does the distribution  $p(c)$ . The point-seeing probability could have been derived without regard to a finite area field-of-view. Staying strictly in the time domain one figures that the probability of seeing a point target is just the average fractional time that the point is cloud free. The distribution  $p(c)$  for a point observing area becomes a two point distribution (at the end points  $c = 0$  and  $c = 1$ ), and the mean cloud cover is then just  $\bar{c} = 1 \cdot p(1)$ . The interchange of space and time statistics can generally be made because of the dynamic nature of clouds and cloud systems.

K.2 FINITE-AREA SEEING PROBABILITY. An agricultural mission requirement is - loosely stated - that a finite-area sample site be observed relatively cloud free. Too much cloudiness over the sample site will result in (a) a loss of pixel by pixel information in direct proportion to the amount of cloud covered area, (b) a processing system burden in terms of cloud recognition and field boundary determination, and (c) a difficult-to-assess loss of confidence in the data vector because of the complex operations involved in (b). The requirement of relatively cloud free sample sites could be translated into the requirement of low cloud cover (0 - 3/10 say) for the conventional observing area of 30n. mi. The requirement is roughly translatable because, for the most part, observations of low cloudiness will correspond to widely scattered small cumuli that are not likely to blot out significant portions of the sample site area.

However, very small cumulus (the cumulus humilis) could still "pepper" the sample site, and result in an operational data processing burden and loss of data quality. Yet, a requirement of less than 3/10 cloud cover could be too stringent. A requirement that is free of the uncertainty implicit in the

"clear or only slightly cloudy" requirement is that the entire sample site (or some definite subdivision of the sample area) be observed entirely cloud free. The a priori probability of observing a perfectly cloud free finite-area sample site can fortunately be calculated on the basis of empirical distributions presented in the 1971 North American Rockwell ERTS Cloud Cover Study (Reference 1). In the North American Rockwell study several hundred U-2, Apollo, and ESSA satellite photographs were analyzed for the fractional area (of a frame) occupied by cloud-free square resolution elements of various sizes. The fractional area is defined as the total number of cloud free square resolution elements contained in a frame times the area of the resolution element divided by the total area of the frame. Statistics were generated for resolution element sizes of 30 by 30 m (U-2 photographs) to 1000 by 1000 km (ESSA film frames). The fractional cloud-free area statistics depend on the cloud type and organization, and can not be represented simply as functions of the overall cloud cover amount. For example, with evenly scattered cumulus the chances of finding a cloud-free resolution cell with dimensions much larger than the average between-cloud distance will be small; but if, for example, the cumulus clouds are organized into rows, the clear lanes between rows will admit much larger cloud-free resolution cells, even for the same cloud cover amount. Still, one can lump all statistics together to form the conditional expectation, the mean fraction of cloud-free area occupied by resolution cells of a given size for a given cloud cover amount. Call this mean fractional area  $f(x, c)$ .  $x$  is the linear size of the square resolution element, and again  $c$  is the cloud cover amount. Strictly,  $f(x, c)$  will have an explicit dependence (in addition to the implicit dependence through  $c$ ) on region, season, and time-of-day because different cloud organ-

izations will be preferred in different regions and seasons, and at different times of day. This explicit dependence will be ignored in the following, not without some reason. In the Rockwell study (Reference 1) it is suggested that cumulus statistics (size distributions) are essentially similar over uniform terrain, regardless of geographical location. We note that it is with cumulus cloud cover that we must mostly deal (since, especially in summer, cumuli represent most of the broken cloud cover), and that a major portion of the temperate zone agricultural productivity is on the level plains of North America and Eurasia.

Figure K-2, from the referenced Rockwell report represents a grand summary of the Rockwell photograph analyses. The ordinate is  $f(x, c)$ , the mean fractional area of cloud-free resolution cells in percent, and the abscissa is the square element size  $x$  in kilometers. The curves are arranged according to ten percent cloud amount intervals. The curve for a given cloud amount is indicated by the value of  $f(x, c)$  at  $x = 0$  (perfect resolution), since  $f(0, c) = 1 - c$ . Table K-1 is constructed from the data of Figure K-1. It provides values of  $f(x, c)$  for  $x = 0, 1, 4$ , and 10 (statute) miles and for cloud amounts in five cloud cover categories (1 = 0%, 2 = 20%, 3 = 45%, 4 = 75% and 5 = 100% cloud cover) for the cloud cover impact calculations to follow. The a priori probability of seeing an  $x$ -mile square resolution element perfectly cloud free given a cloud cover amount  $p(\text{seeing } x/c)$  is identified with the mean fractional area,

$$p(\text{seeing } x/c) = f(x, c).$$

This identification follows the same line of reasoning used in establishing the point seeing probability.. Note that for perfect resolution( $x=0$ )equation 3



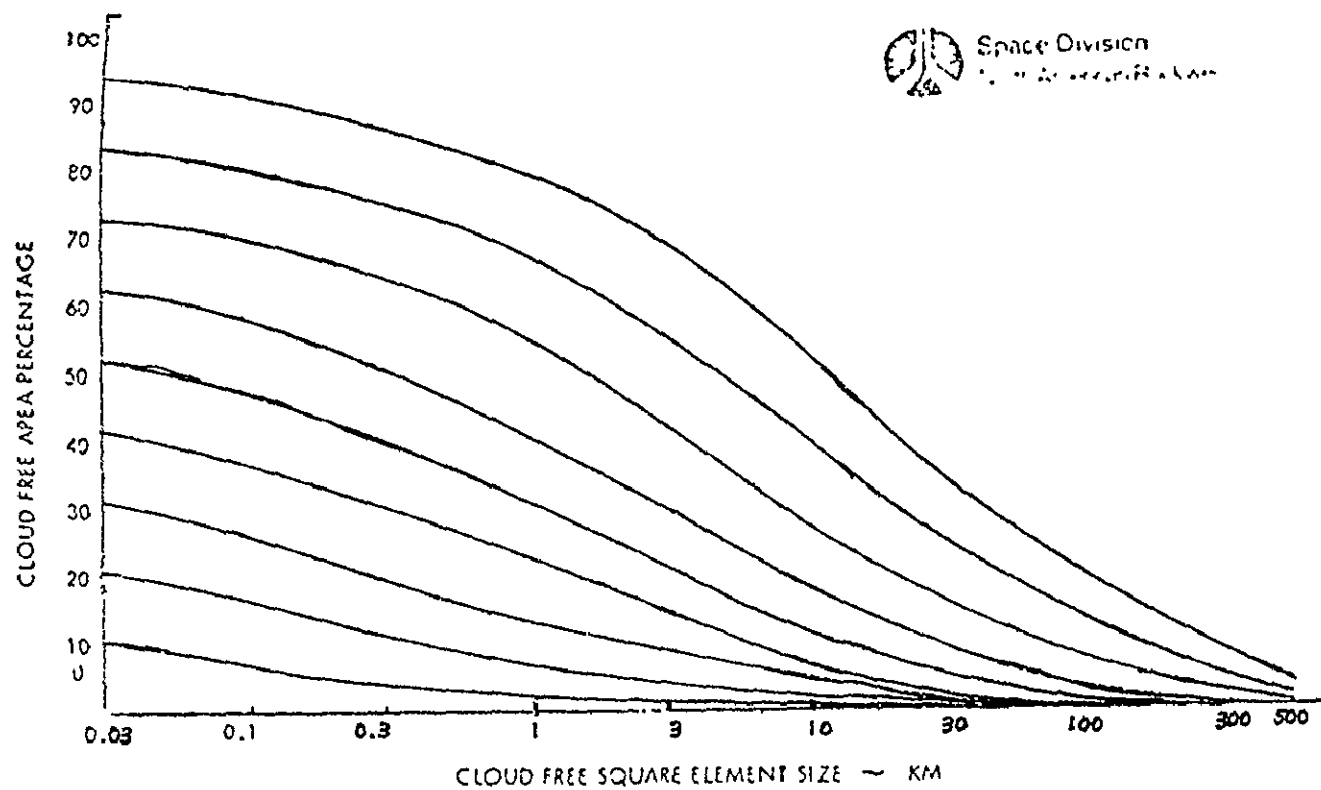


Figure K-1 Combined Statistics for Cloud-Free Resolution Elements in  
10-Percent Cloud Amount Intervals

TABLE K-1

Average Fractional Area  $f(x, c)$  Occupied by  
 $x$ -mile Square Cloud-Free Resolution Elements  
 Versus Cloud Cover Category.

		Cloud-Cover Category				
Square elements size statute miles	$c =$ $x =$	1	2	3	4	5
	0	1	.80	.55	.25	0
	1	1	.59	.30	.09	0
	4	1	.43	.18	.05	0
	10	1	.31	.11	.025	0

reduces to equation 1:  $p(\text{seeing } 0/c) = f(0,c) = 1-c$ . The total a priori probability of seeing a finite sample area given the occurrence of any possible cloud cover is:

$$(4) \quad p(\text{seeing } x) = \sum_c p(\text{seeing } x/c)p(c);$$

$$p(\text{seeing } x) = \sum_c f(x,c) p(c)$$

In the computations following, the cloud cover categories  $\bar{c} = 1, 2, \dots, 5$  are used and the summation extends from  $c = 1$  to  $c = 4$  (since for overcast sky  $c = 5$ ,  $f(x, 100\%) = 0$ ). Using the  $f$ -values in Table K-1 for  $x = 4$  miles, we have, for example,

$$p(\text{seeing } 4 \text{ miles}) = 1 \cdot p(1) + .43 p(2) + .18 p(3) + .05 p(4)$$

Table K-2 shows the single-site (single satellite pass) finite-area seeing probabilities for several observing stations in July 1000 LST (Local standard time). It is worth noting that the 1-mile seeing probabilities are numerically very nearly equal to the probabilities of less than 3/10 cloud cover. This numerical coincidence appears to hold for a wide variety of different cloud cover distributions, and can be taken as general rule of thumb. This numerical coincidence (for the 1-mile resolution element) is convenient. It allows us to use cloud atlases for the frequency of occurrence of less than 3/10 cloud cover. Lastly we remark that the finite-area seeing probability will always be bounded by the extremes,

$$(5) \quad p(1) \leq p(\text{seeing } x) \leq 1 - \bar{c}.$$

K.3 MULTIPLE - LOOK SEEING PROBABILITIES. Let  $P_1$ , stand for the single-site, single-pass seeing probability, Equation 4. The probability of seeing the sample-site at least once in  $n_t$  independent temporal trials (satellite passes) assuming that  $P_1$  is temporally stationary is given by the well-known combinatorial

TABLE K-2

Cloud Cover Distributions and Seeing Probabilities  
For Some US and European Stations

a Station	Relative frequency of cloud cover category (in percent) b					mean cloud cover	Single pass seeing probability for x mi. square sample area				Probability of less than 30% cloud cover  =P(1)+P(2)
	1	2	3	4	5		0 mi.	1 mi.	4 mi.	10 mi.	
Des Moines, Iowa	21.4	17.6	7.9	23.7	29.3	.54	.46	.36	.32	.28	.39
Cheyenne, Wyo.	39.3	23.5	7.0	18.1	11.9	.34	.66	.57	.52	.50	.63
Grand Is. Neb.	35.0	18.3	7.9	18.5	20.1	.41	.59	.50	.45	.42	.53
Washington, D.C.	14.3	16.2	10.4	31.6	27.5	.59	.41	.30	.25	.21	.31
Belleville, Ill.	13.3	17.5	11.9	32.7	24.8	.58	.42	.30	.25	.21	.31
Fresno, Calif.	80.0	8.0	3.0	7.0	2.0	.10	.90	.86	.84	.83	.88
Schreveport, La.	12.0	22.0	17.0	32.0	17.0	.53	.47	.33	.26	.21	.34
Brandon, England	2.0	7.0	10.0	46.0	35.0	.73	.27	.13	.09	.06	.09
Furth, Germany	3.0	15.0	12.0	30.0	40.0	.71	.29	.18	.13	.10	.18

a. U.S. data for July - 1000, LST; European data for summer 1600 LST

b. The cloud cover categories correspond to the nominal sky covers: 1 = clear, 2 = 20%

3 = 45%, 4 = 75%, and 5 = overcast. Data from references 1 and 2

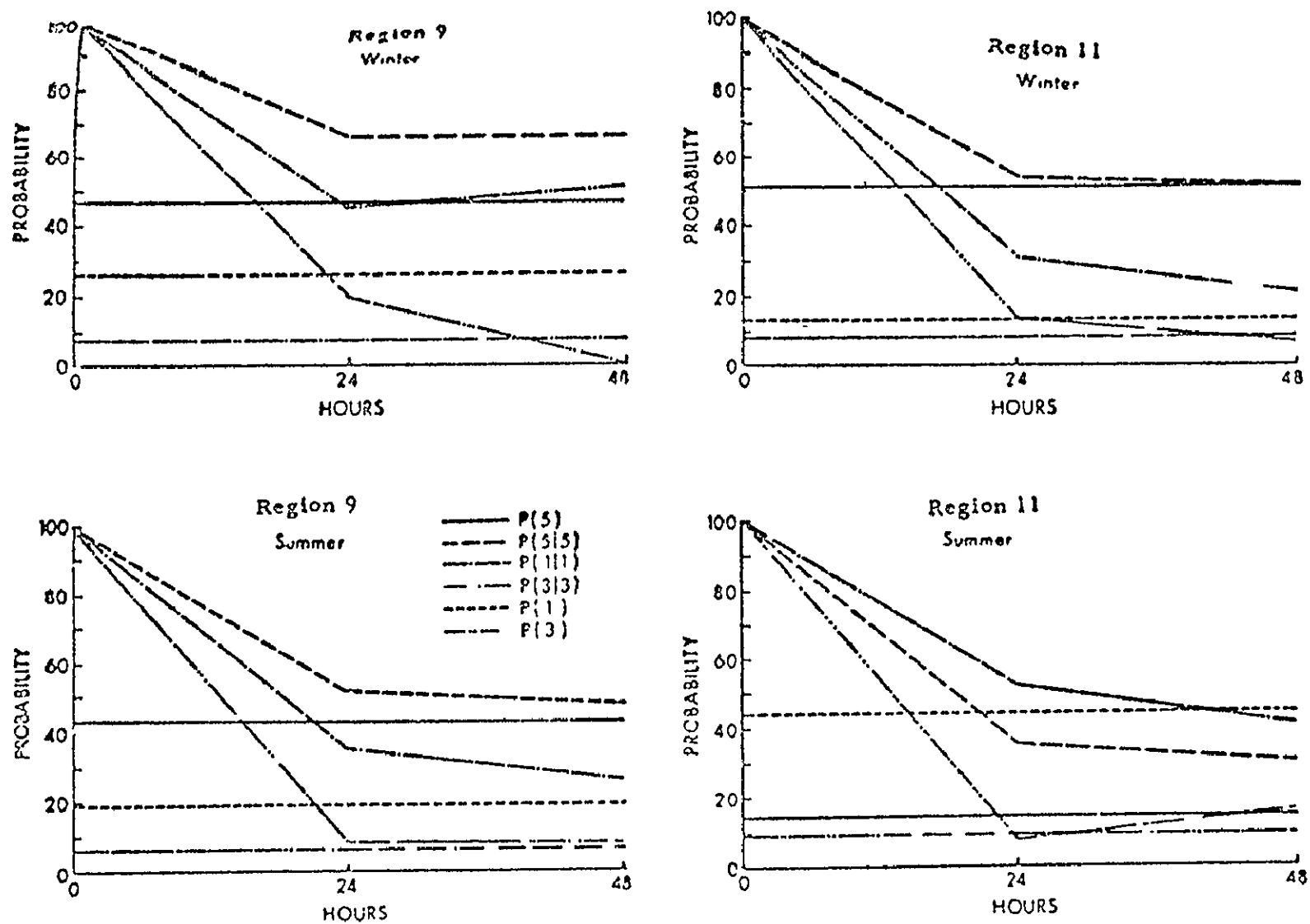


Figure K-2 Comparison of Decay of Temporal Conditionals with Time for Regions 9 and 11

formula

$$(6) \quad p(\text{seeing } x \text{ in } n_t \text{ passes}) = 1 - (1 - p_1)^{n_t}.$$

$(1 - p_1)^{n_t}$  is the probability of not seeing the sample site in  $n_t$  passes. The time required between looks to achieve statistical independence depends basically on whether a region is subject to frequent synoptic disturbances (temperate climates). With a monotonous convective cloud climate, statistical independence can be expected on the order of hours, certainly in less than a day. This is because of the advection and dynamic evolution of individual cloud elements in the homogeneous, statistically stationary cloud regime. However, in midlatitude temperate climates, there is an appreciable frequency of clear sky occurrences associated generally with synoptic scale high pressure systems. Because the seeing probabilities are so strongly weighted by the probability of clear skies, it is necessary to know the time scale for the persistence of clear skies. In the Allied Research study (Reference 2), temporal conditional probabilities were computed for the several cloud categories. Figure K-2 from the Allied Research study shows the decay of several conditional probabilities with time, including the clear sky conditional  $p(1/1)$ , for the important temperate Region 11 (Belleville, Ill.) in the summer. The figure shows that clear sky persistence is on the order of 24 hours, and that the occurrences of clear skies more than two days apart can be regarded as nearly independent events. From the figure it appears that the persistence of solid overcast (category 5) is greater than 2 days. A time scale of 3-4 days corresponding to the generally observed synoptic cycle appears to be a reasonable time scale to adopt for independence of cloud cover occurrences.

K.4 MULTIPLE-SITE, MULTIPLE LOOK SEEING PROBABILITY. Consider an area on the ground the size of an ERTS frame (100 by 100 n. mi.). Suppose that

inside the frame there are  $n_s$  sample sites. The sampling areas are all squares of  $x$  miles on a side, and the distance between samples is "large" compared to  $x$ . We ask" what is the probability of having successfully observed, perfectly cloud free, at least  $k_s$  of the  $n_s$  sample areas after  $n_t$  independent trials (looks)? Or alternatively, we ask: what is the maximum number of samples  $k_s$  we can expect to observe with a given degree of confidence, or probability? Consider the two mutually exclusive events:

$e$ : clear sky (over the entire frame) occurs at least once during the  $n_t$  trials (looks);

$\tilde{e}$ : no clear sky occurs in the  $n_t$  trials.

Let  $p(k)$  be the probability of successfully observing exactly  $k$  out of the  $n_s$  finite-area sample sites after  $n_t$  independent temporal trials.

From the exclusivity of the two events  $e$  and  $\tilde{e}$  we have

$$(7) \quad p(k) = p(k/e) p(e) = p(k/\tilde{e}) p(\tilde{e})$$

Since for a clear sky occurrence all  $n_s$  samples are successfully observed,  $p(k/e) = \delta_{k,n_s}$  where  $\delta_{k,n_s}$  is the Kronecker delta. The probability of one or more clear sky occurrences in  $n_t$  independent trials  $p(e)$  is given by the combinatorial formula

$$(8) \quad p(e) = 1 - [1 - p(1)]^{n_t}$$

where  $p(1)$  is the probability of category 1 (clear sky) occurrence for a nominal 100 n. mi. frame area. Since either of the events  $e$  or  $\tilde{e}$  must occur,  $p(e) + p(\tilde{e}) = 1$ ; so

$$p(\tilde{e}) = 1 - p(e) = (1 - p(1))^{n_t}$$

Thus Equation 7 can be written as

$$(9) \quad p(k) = \left\{ 1 - (1 - p(1))^{n_t} \right\} \delta_{k,n_s} + p(k/\tilde{e}) (1 - p(1))^{n_t}$$

The event  $\tilde{e}$  (no clear sky occurrence) consists only of combinations of partly cloudy and overcast occurrences. We shall assume that for any partly cloudy

occurrence (categories 2,3, and 4) the seeing events at individual sample sites are independent. This assumption is difficult to support without some "hand waving"; however it does seem to be a fairly reasonable assumption.

#### K.5 THREE-CLASS MODEL

The analysis is considerably simplified if the partly cloudy categories 2,3 and 4 are lumped together into one "broken cloud" category:

Let

$$(10) \quad p_b = p(2) + p(3) + p(4)$$

be the probability of occurrence of broken cloud cover. Let the single-site, single-look seeing probability given broken cloud cover be defined by

$$(11) \quad f_b = \frac{f(x,2)p(2) + f(x,3)p(3) + f(x,4)p(4)}{p(2) + p(3) + p(4)}$$

Under the event  $\tilde{e}$  suppose there are  $t$  ( $0 \leq t \leq n_t$ ) occurrences of broken cloud cover in any order. Given this event, the single-site seeing probability after  $n_t$  trials is

$$(12) \quad p_t = 1 - (1 - f_b)^t.$$

Because of the assumed independence under broken cloud cover of the  $n_s$  site seeing events, the probability of seeing  $k$  out of  $n_s$  successfully is given by the binomial distribution for  $n_s$  Bernoulli trials with the single trial probability parameter  $p_t$ :  $p(k/t) = b(K;n_s,p_t)$  where the binomial distribution is given by

$$(13) \quad b(k;n_s,p_t) = \frac{n_s!}{k!(n_s-k)!} p_t^k (1-p_t)^{n_s-k}$$

The probability of  $t$  broken cloud cover occurrences in  $n_t$  trials given  $\tilde{e}$  (only broken cloud cover or overcast conditions) is also given by a binomial



distribution:  $p(t/\tilde{e}) = b(t; n_t, p_b')$  where  $p_b'$  is the probability of broken cloud cover given  $\tilde{e}$ , viz.,

$$(14) \quad p_b' = \frac{P_b}{1-p(1)}$$

The probability of successfully seeing exactly  $k$  out of  $n_s$  sites after  $n_t$  independent looks given no clear skies can now be writtem as

$$(15) \quad p(k/\tilde{e}) = \sum_{\kappa=0}^{n_t} b(k; n_s, p_\kappa) b(\kappa; n_t, p_b')$$

For  $t = 0$ ,  $p_t = 0$  and  $b(k; n_s, 0)$  is by definition zero for  $k \neq 0$  and unity for  $k = 0$ . Combining equations 15 and 9 we have finally for the probability of seeing exactly  $k$  out of  $n_s$  sites after  $n_t$  looks:

$$(16) \quad p(k) = \left\{ 1 - [1 - p(1)]^{n_t} \right\} \delta_{k, n_s} + [1 - p(1)]^{n_t} \sum_{\kappa=0}^{n_t} b(k; n_s, p_\kappa) b(\kappa; n_t, p_b')$$

As a check on (16), the expected number of successful observations is calculated:

$$\bar{k} = \sum_{k=0}^{n_s} k p(k) = n_s \left\{ 1 - [1 - p(1)]^{n_t} \right\} + [1 - p(1)]^{n_t} \sum_{\kappa=0}^{n_t} n_s p_\kappa b(\kappa; n_t, p_b')$$

Using (12) for  $p_t$ , and recognizing some binomial expansions, we find:

Using (14) for  $p_b'$  we then have for  $\bar{k}$ :

$$(17) \quad \bar{k} = \left\{ 1 - [1 - p(1) - f_b p_b]^{n_t} \right\} n_s$$

we recognize  $p(1) + f_b p_b = \sum_c f(\kappa, c) p(c)$

as the single-site seeing probability, and  $1 - [1 - p(1) - f_b p_b]^{n_t}$  as the single-site,

multiple look seeing probability. The average number of successful observations

$\bar{k}$  is just the final single-site seeing probability times the number  $n_s$  of sites.

This is what we expect from elementary considerations.

## K.6 LARGE SAMPLE LIMITING FORMS

If  $n_s$  is large and  $n_s p_t(1 - p_t) \gg 1$ , then the distribution  $b(k; n_s, p_t)$

tends toward a normal distribution concentrated at  $k = n_s p_t$ , that is, a normal distribution with mean  $n_s p_t$  and standard deviation  $\sqrt{n_s p_t (1 - p_t)}$ . Consider the data for Belleville, Ill., June 1000 LST (Table 2). We find that find  $f_b = .18$  ( $x = 4$  mi). Let  $n_s = 100$  and let  $n_t$  be no greater than 10. Then for  $1 \leq t \leq 10$ ,  $.18 \leq p_t \leq .86$ , and  $12.0 \leq n_s p_t (1 - p_t) \leq 50$ . The conditions for the normal approximation are well satisfied. Now, going one step further, we suppose there is no significant overlap of the binomials  $b(k; n_s p_t)$  for  $t = 1, 2, \dots, n_t$  ( $n_t \leq 10$ ), and we approximate the distributions by delta functions located at  $n_s p_1 \dots n_s p_t$  and  $1 - (1 - p(1))^{n_t}$  for  $k = n_s$ .

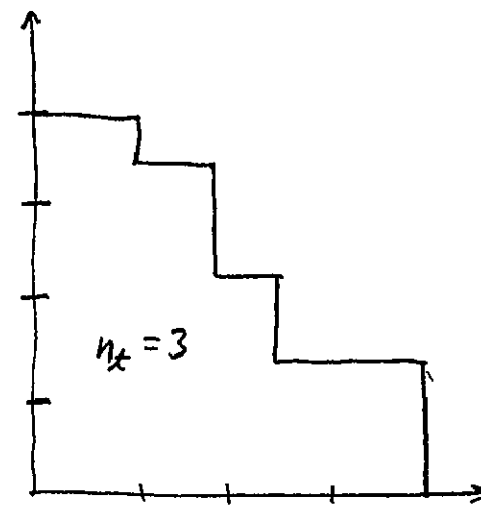
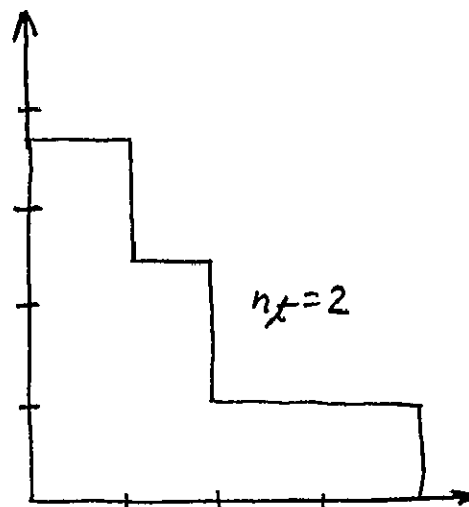
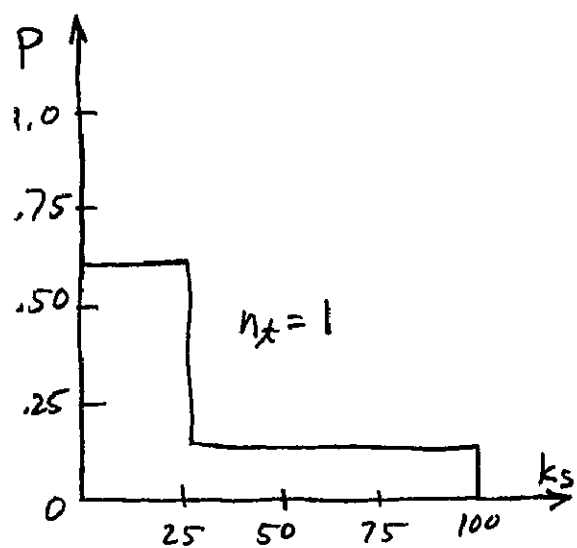
#### K.7 CUMULATIVE DISTRIBUTION

With the above approximations, the cumulative distribution function

$$(18) \quad P(k \geq k_s) = \sum_{k_s}^{n_s} p(k)$$

is easily calculated. The approximation of  $p(k)$  by a series of spikes leads to a staircase function representation of  $P(k \geq k_s)$ . Figure K-3 shows the cumulative distribution  $P(k \geq k_s)$  for Belleville, Ill., June 1000 LST ( $x = 1$  mile). The figure supplies a rough answer to our original question: what is the probability of successfully observing at least  $k_s$  out of  $n_s$  sites after  $n$  satellite passes. To achieve a better representation of the probability function one would have to introduce more classes (for example, one could use all five cloud cover categories); this would entail rather unwieldly multinomial distribution functions. At this point, one might prefer to go the route of full-blown numerical simulation. (Monte Carlo)

The agricultural missions cloud impact model developed here may be compared with the incremental photographic coverage models developed in the Allied and Rockwell reports (References 1 and 2). On repeated passes, photographic coverage is



BELLEUILLE, ILL., JUNE, 1000 LST, ( $\alpha = 1 \text{ mi}$ )

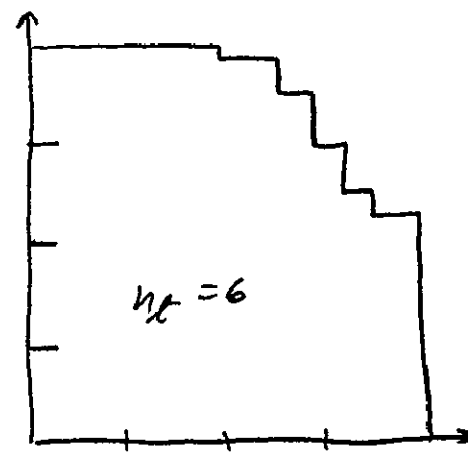
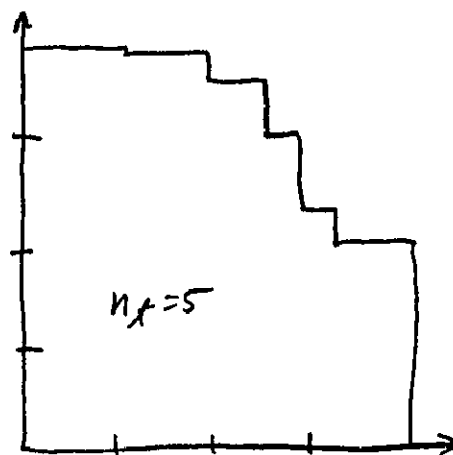
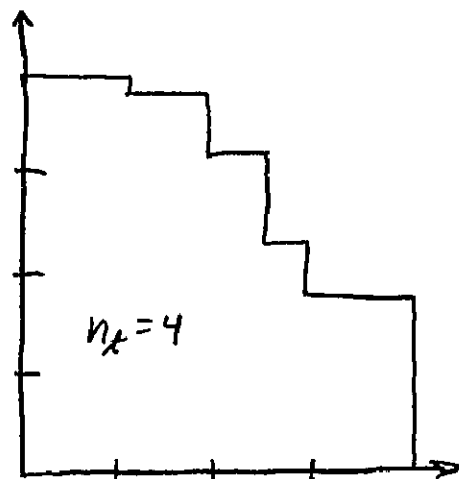


Figure K-3 Three-class Cloud Cover Model  
In the Large Sample Unit

built up by piecing together clear areas. The Allied Study developed a five-class combinatorial model based on an essentially large sample assumption. The Rockwell Study developed a Monte Carlo model as was suggested in the report. The Rockwell simulation results for Region 11 (Belleville, Ill,) July 1000 LST are shown in Figure K-4. Comparing Figure K-4 to Figure K-3 it is seen that the cumulative probabilities of Figure K-3 are constantly lower than the corresponding distributions of Figure K-4. The lower probabilities of seeing for our agricultural missions model compared to those of the photo coverage simulation is evidently due to the conservative finite-area seeing requirement we have adopted.

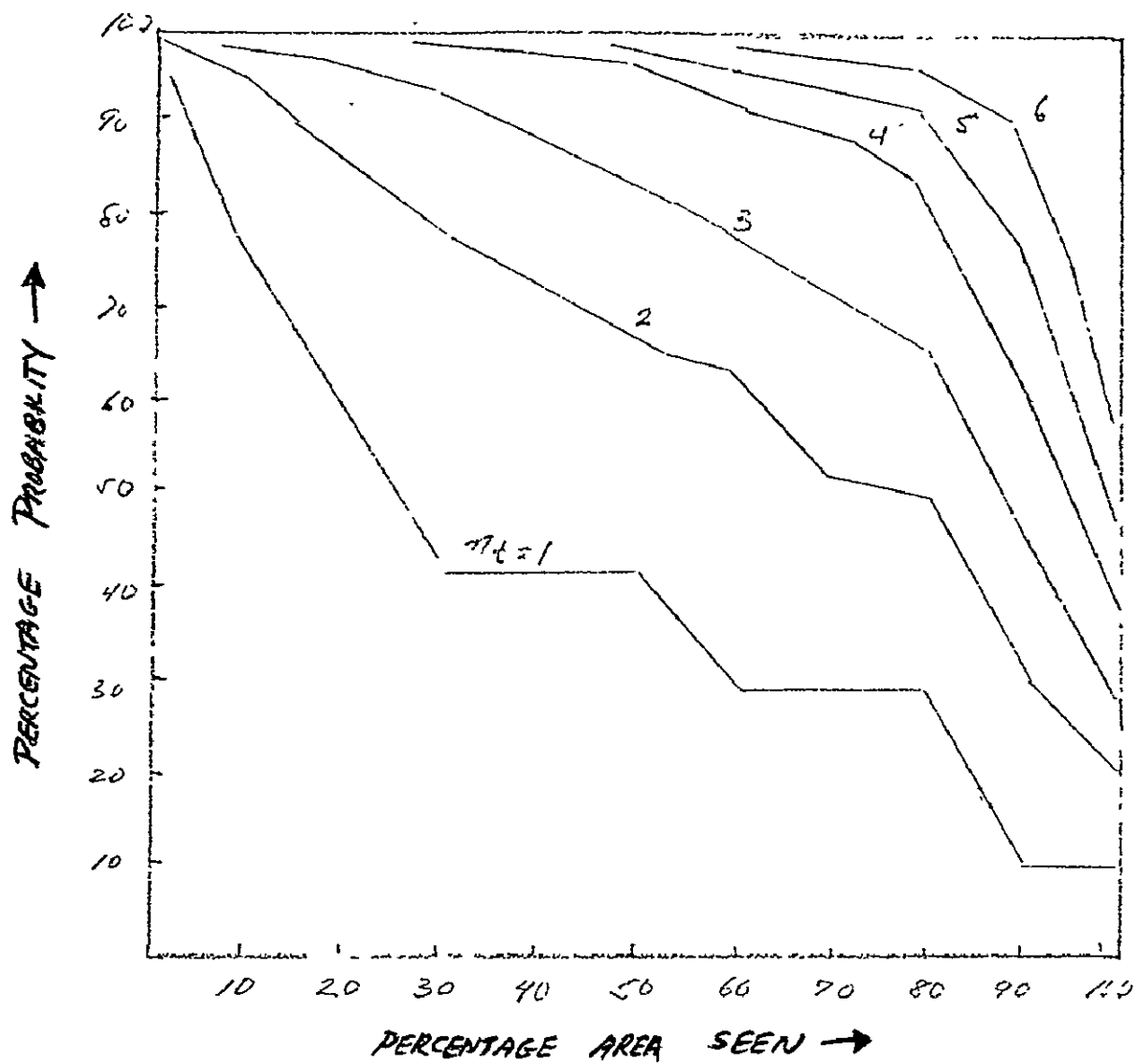


Figure K-4 Rockwell Monte Carlo Results for Incremental Photo Coverage, Region II July 1000 LST

#### REFERENCES

1. C. D. Martin and B. Liley, "ERTS cloud cover study"  
North Am. Rockwell report to NASA/GSFC, contract NAS5-11231, March 1971
2. P. E. Sherr et al., "World-wide cloud cover distribution for use as computer simulations, Allied Research Assoc., Inc. report to NASA/MSFC, NASA CR-61220, 1968

**APPENDIX L**  
**CROP MAPS AND CALENDARS**

## APPENDIX L

### CROP MAPS AND CALENDARS

This appendix summarizes the crop information with respect to crop maps and growth calendars compiled as part of TOSS.

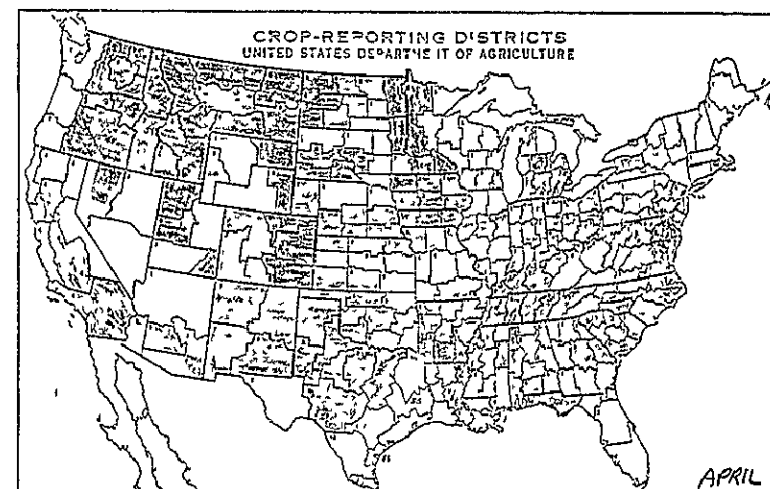
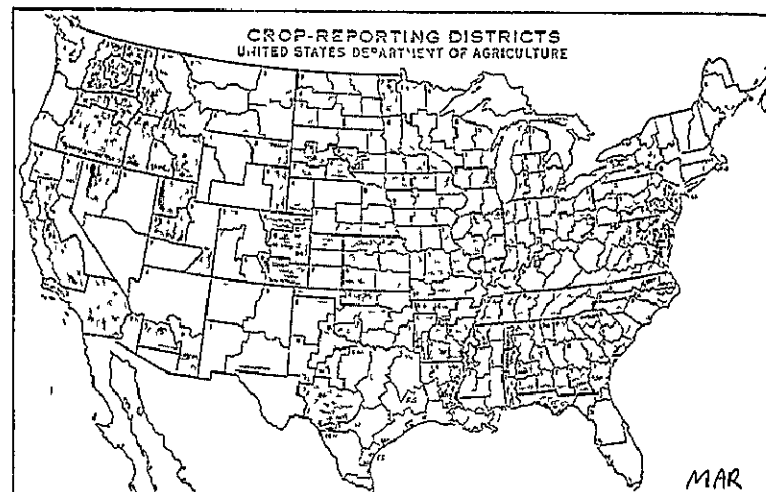
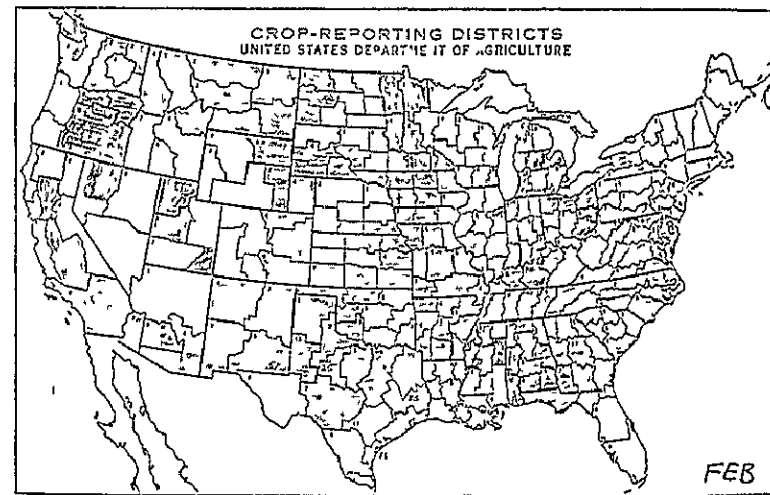
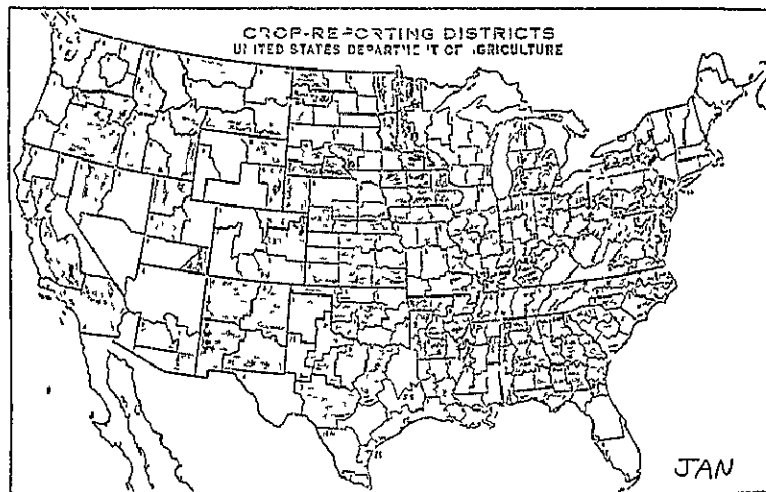
For the U.S. crops of interest, maps are presented by crop, by month, which show the geographical extent and growth stage of each crop. The crops addressed and their sequence are:

Wheat  
Soybeans  
Rye  
Rice  
Oats  
Corn  
Barley

On a global basis, summary maps are presented which show the major growing regions of the world for each crop. The crops and their sequence are:

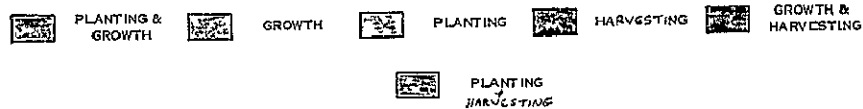
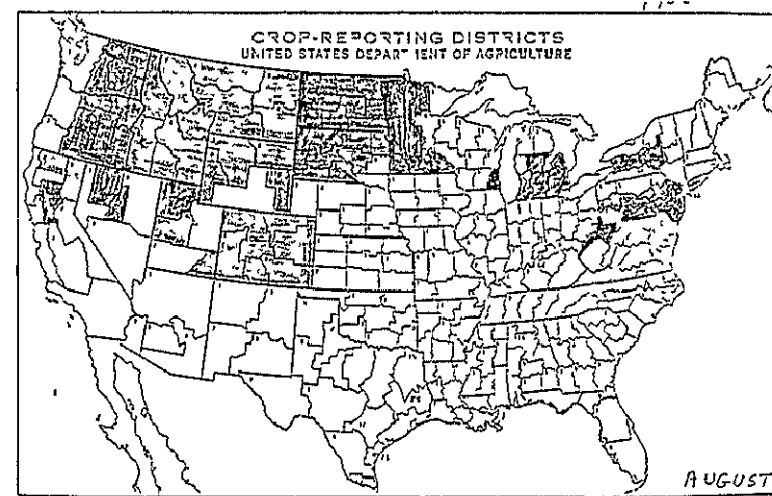
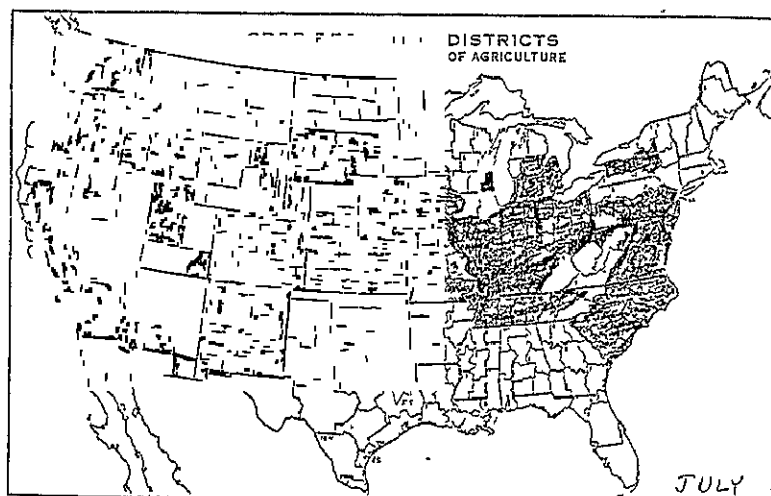
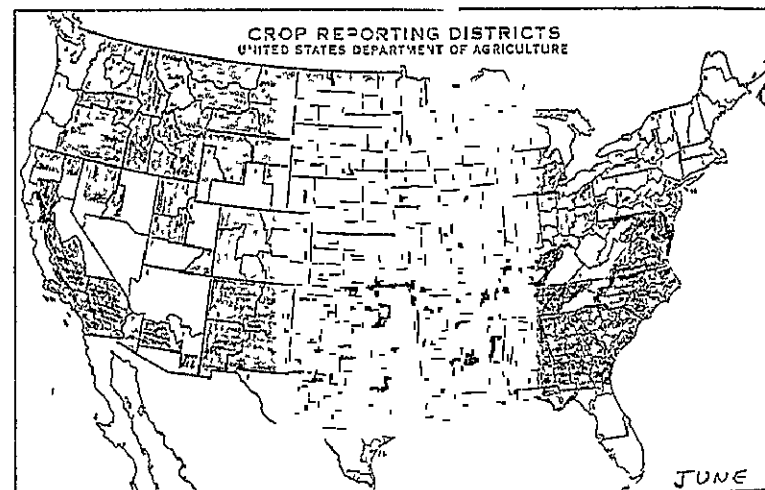
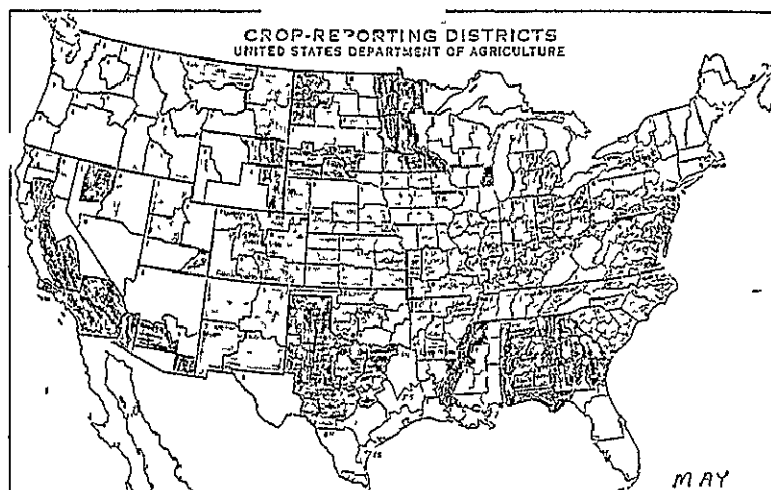
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Barley  
Corn  
Oats  
Rice  
Rye  
Soybeans



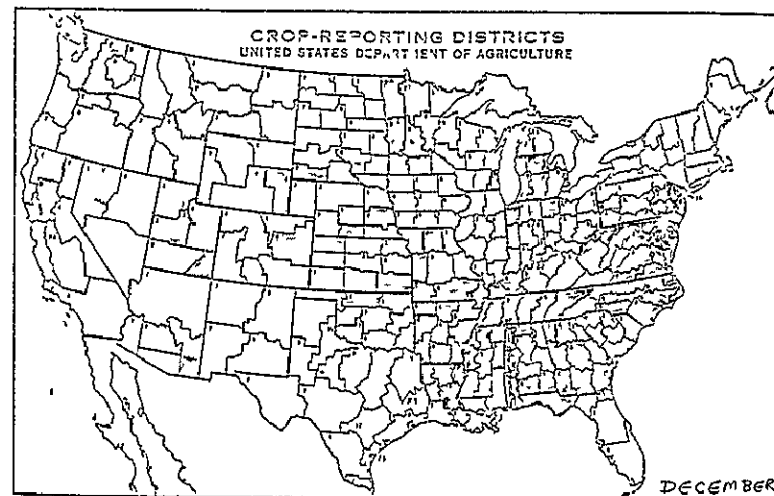
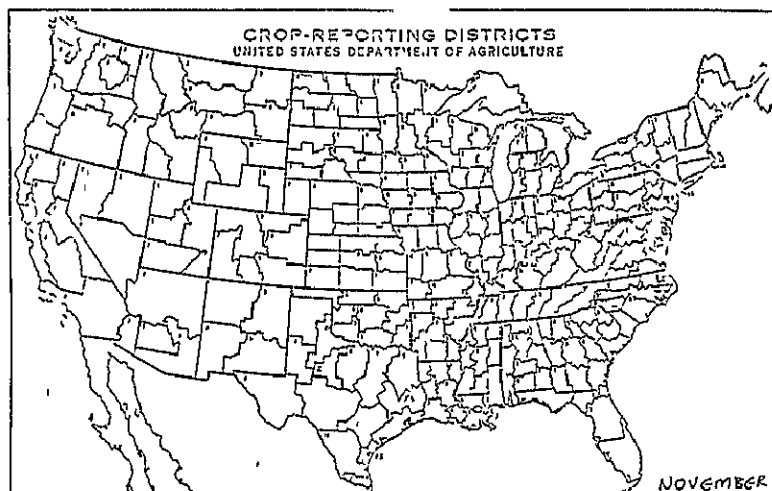
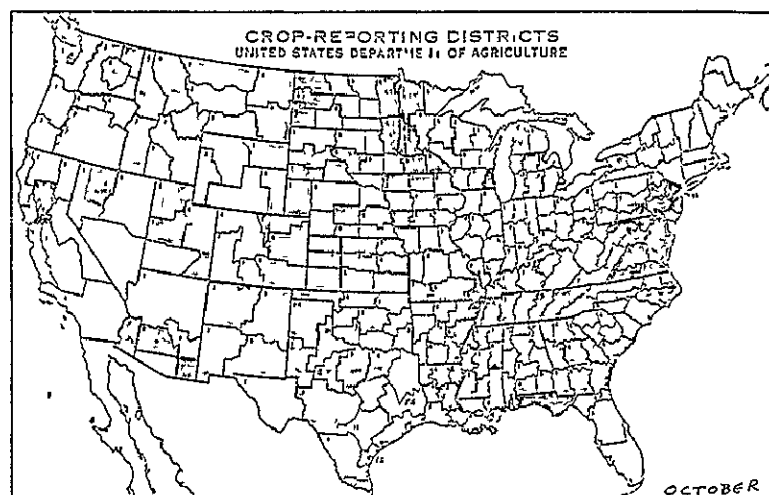
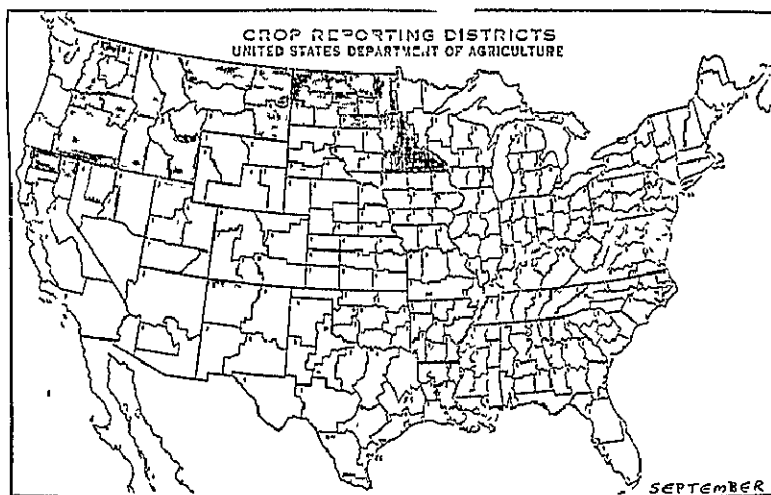


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WHEAT

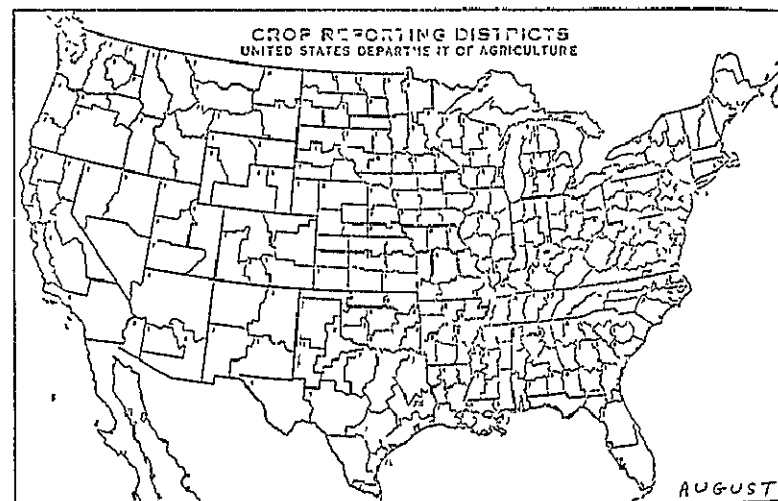
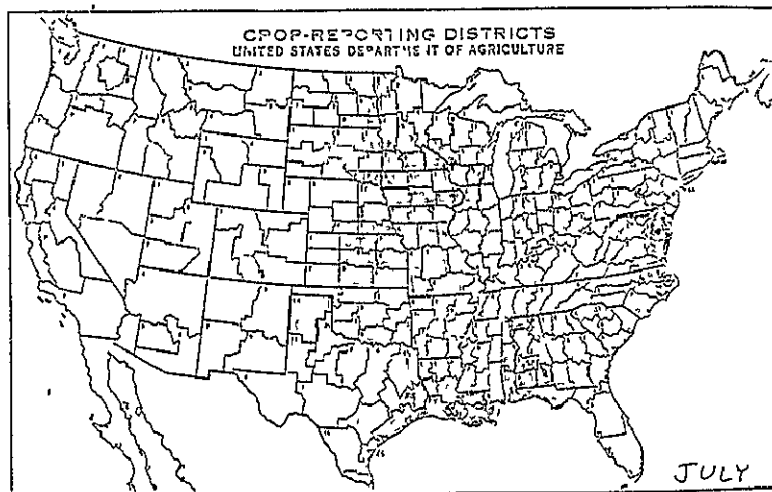
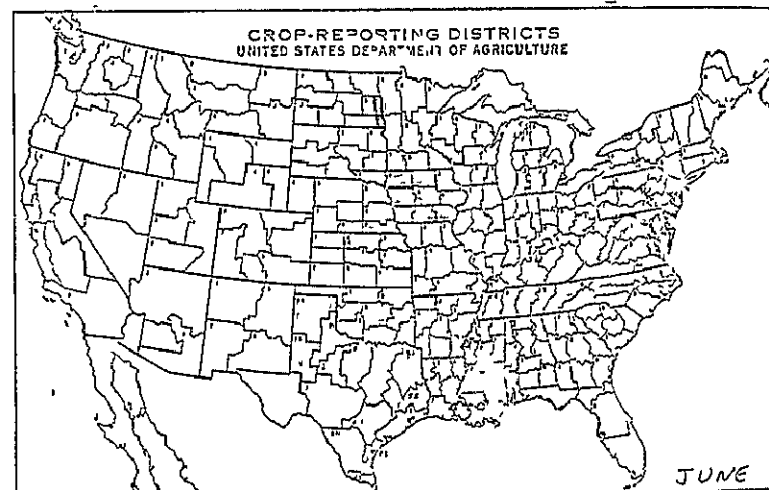
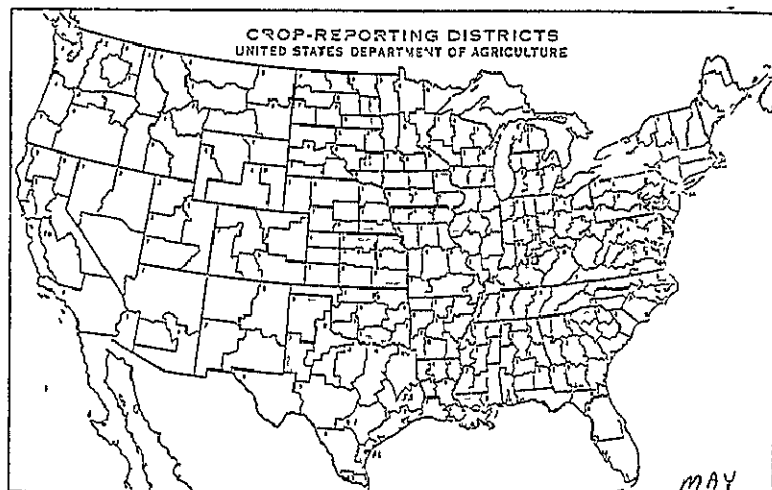


WHEAT



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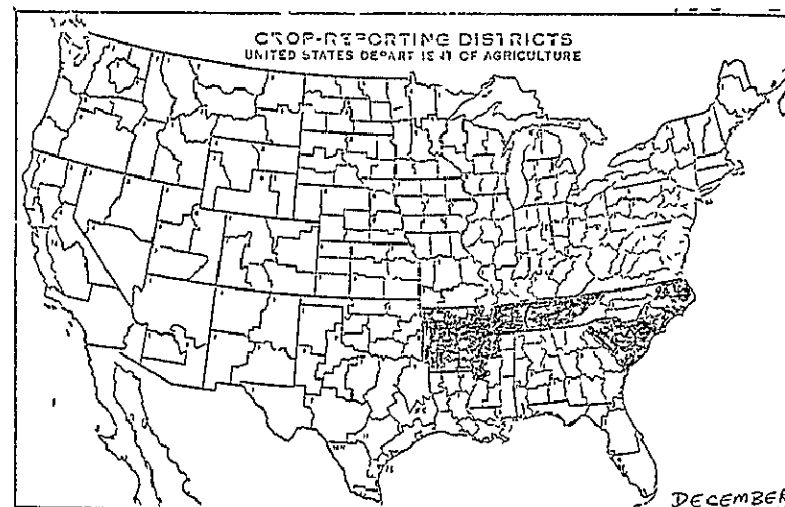
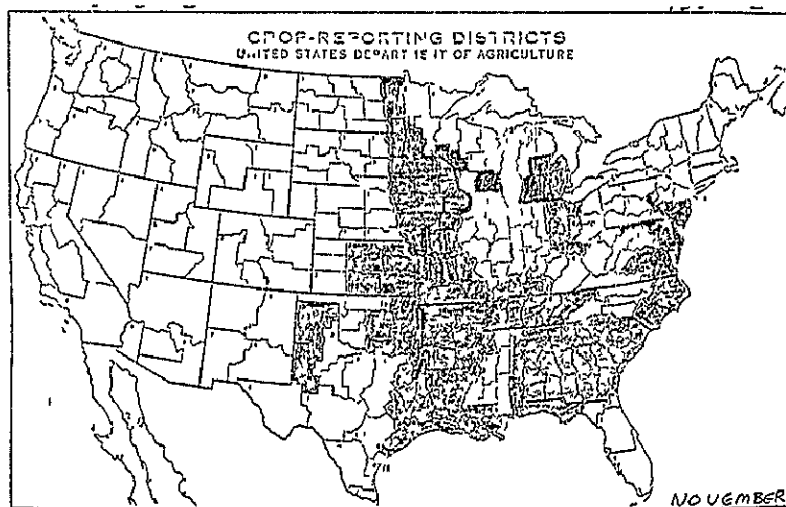
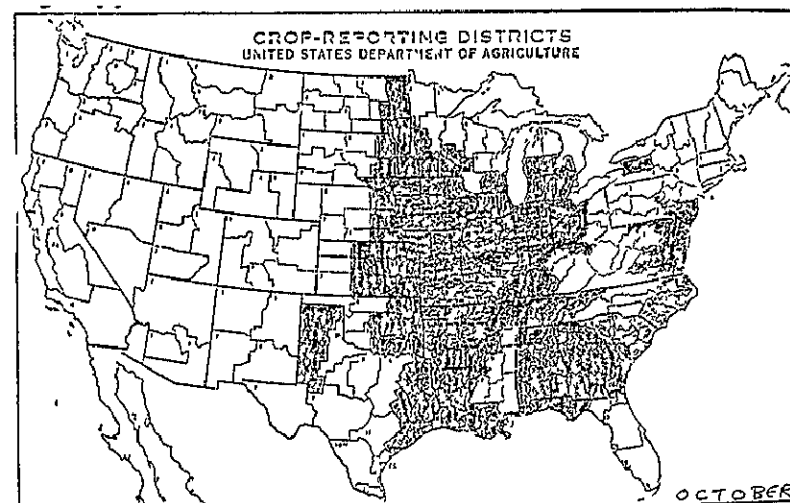
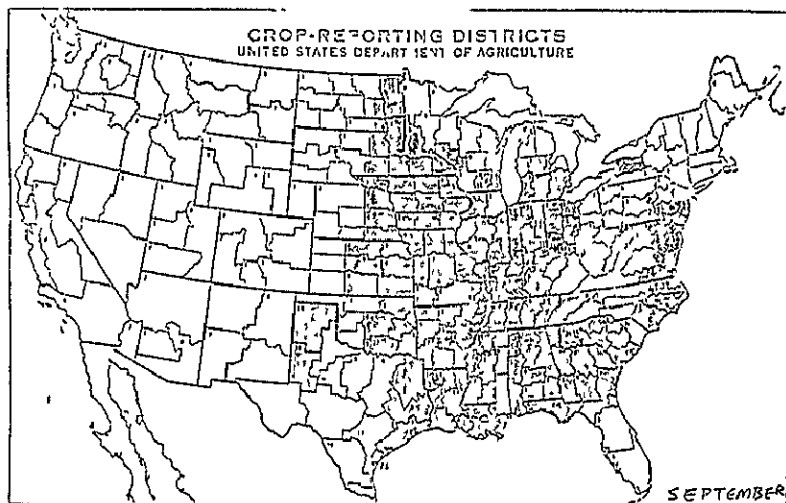


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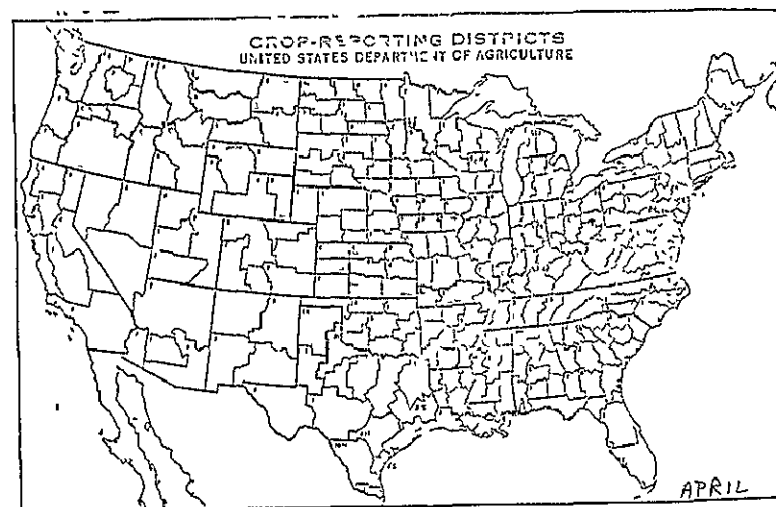
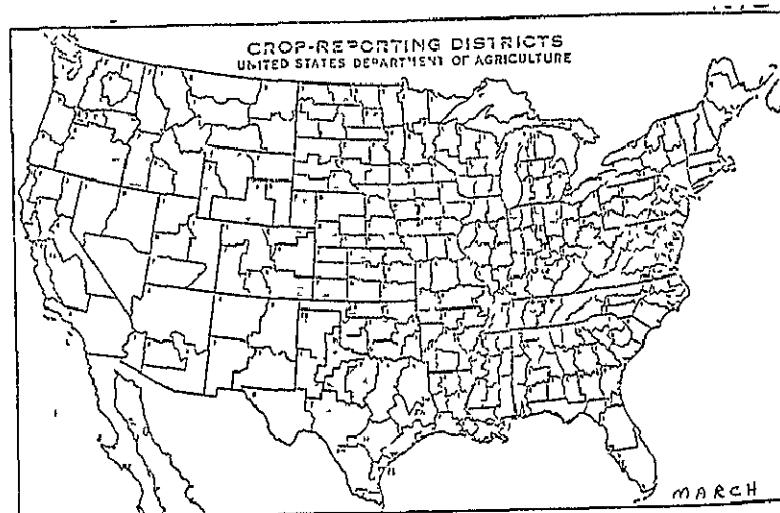
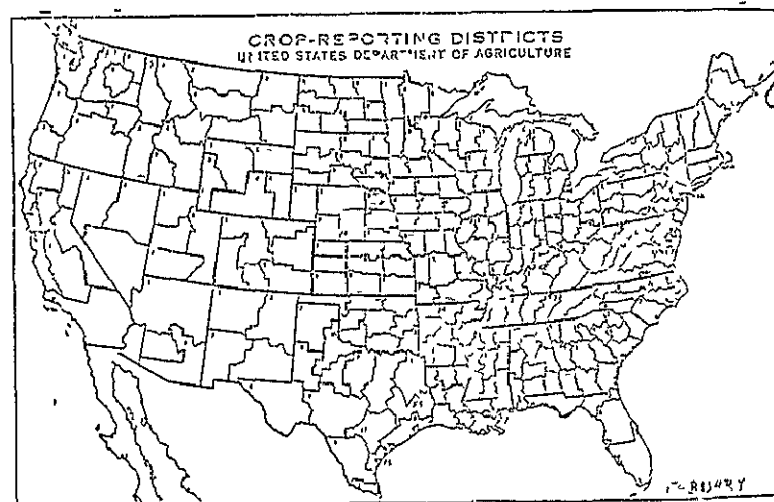
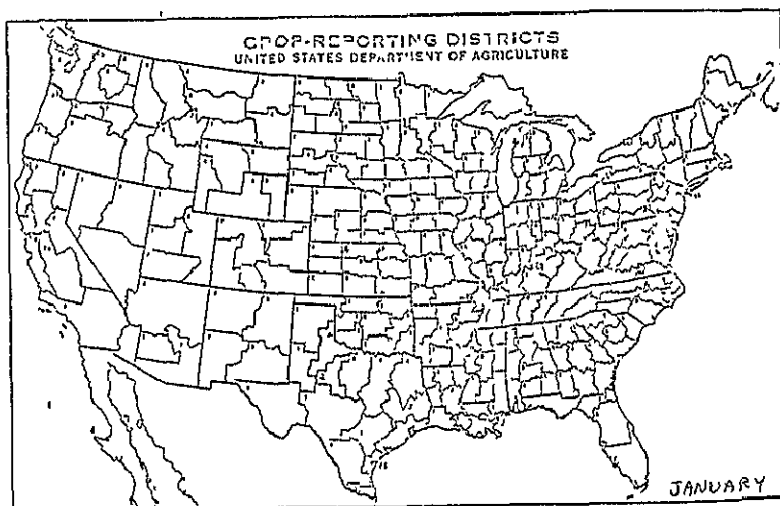


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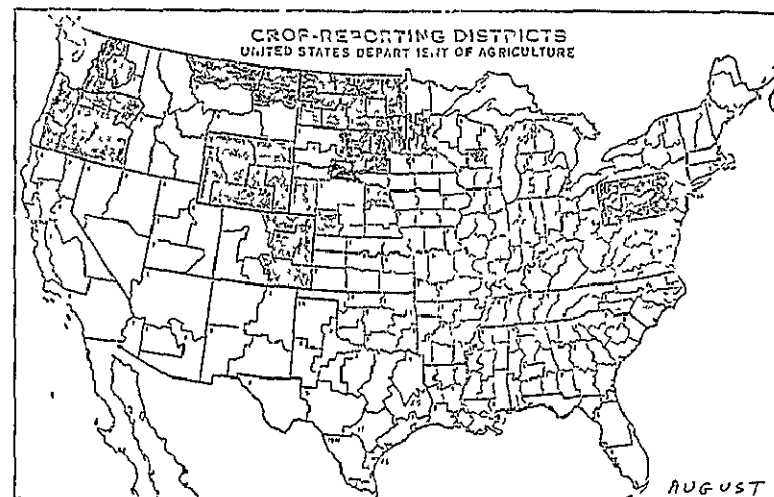
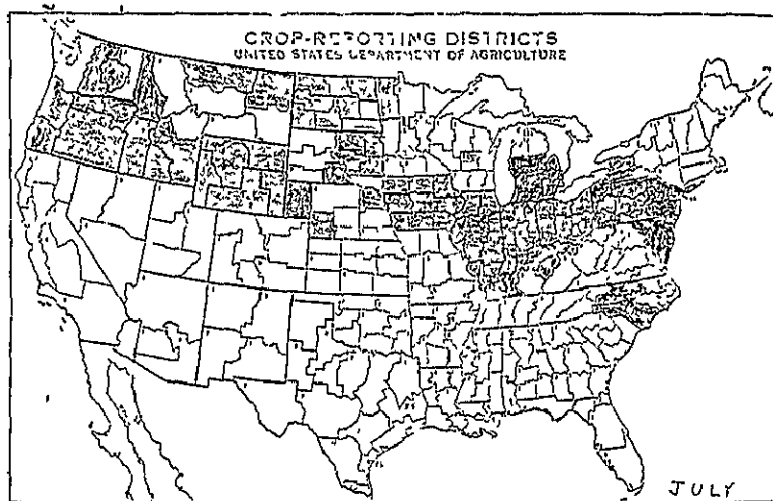
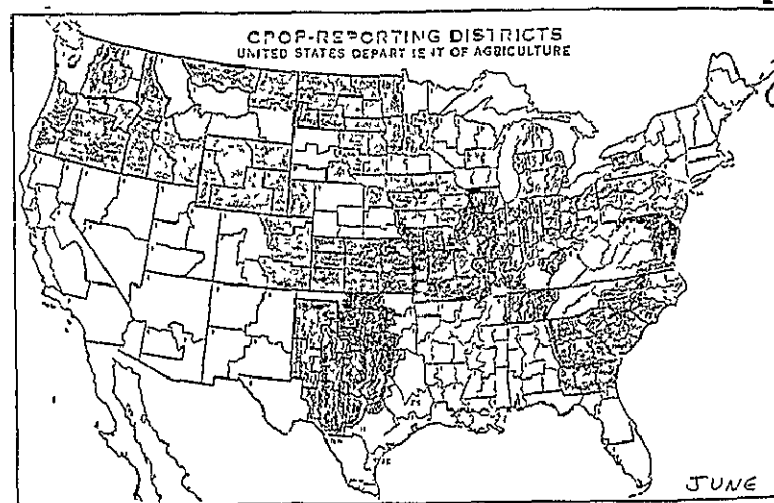
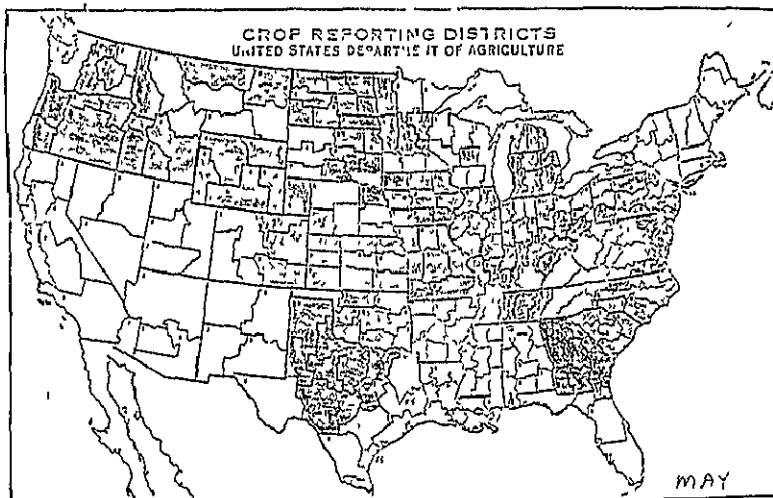
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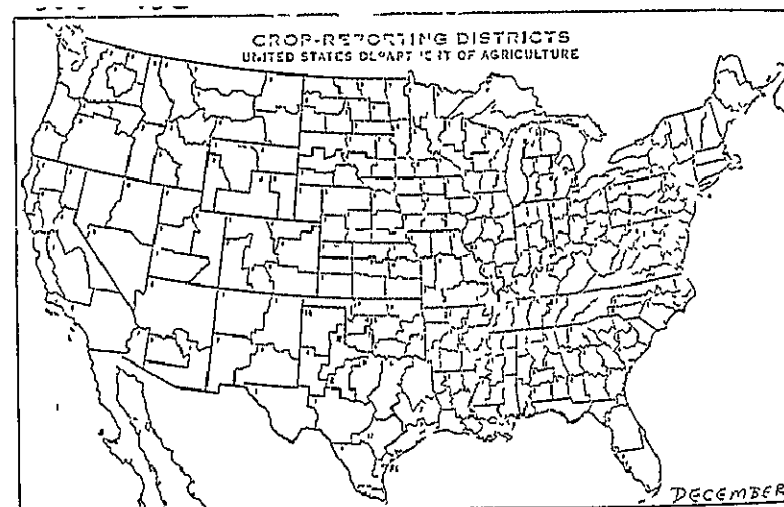
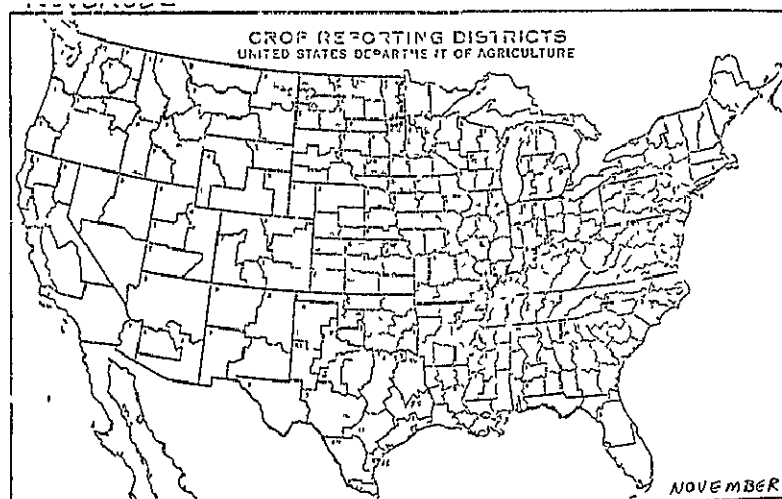
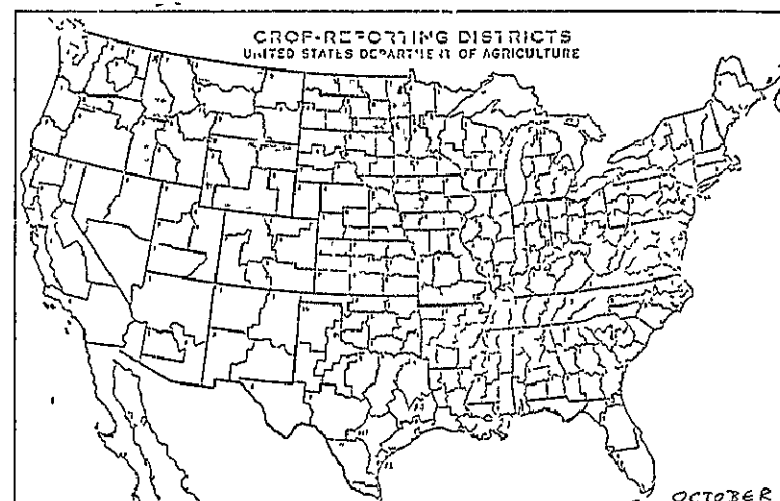
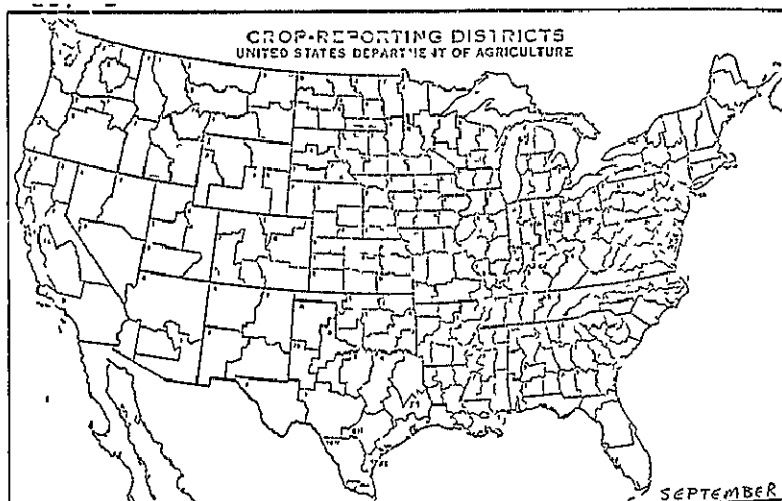
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RYE



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RYE



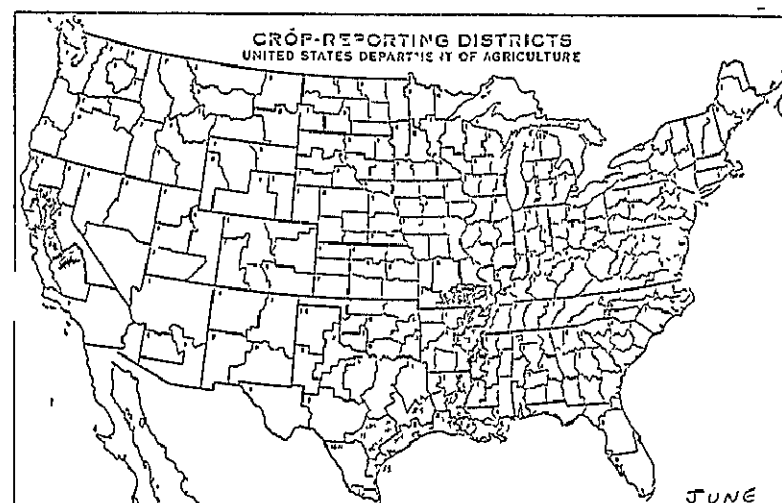
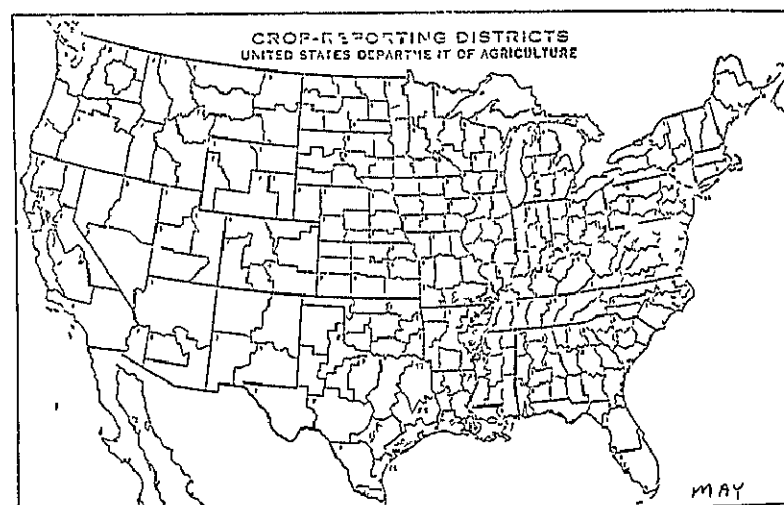
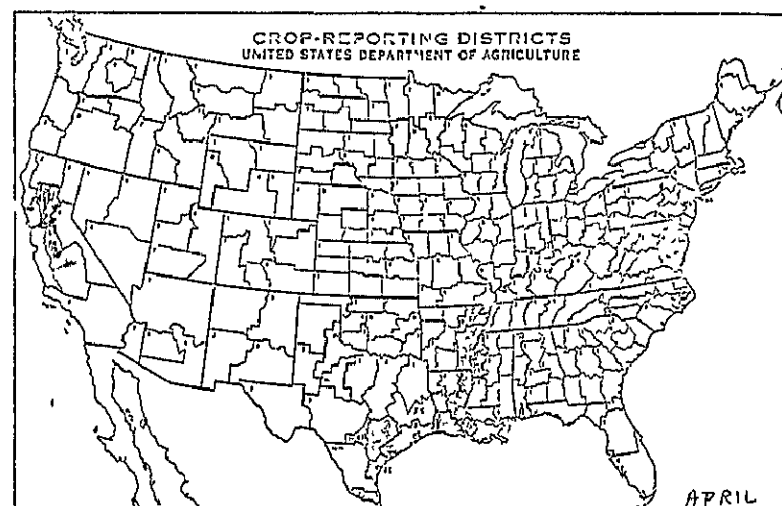
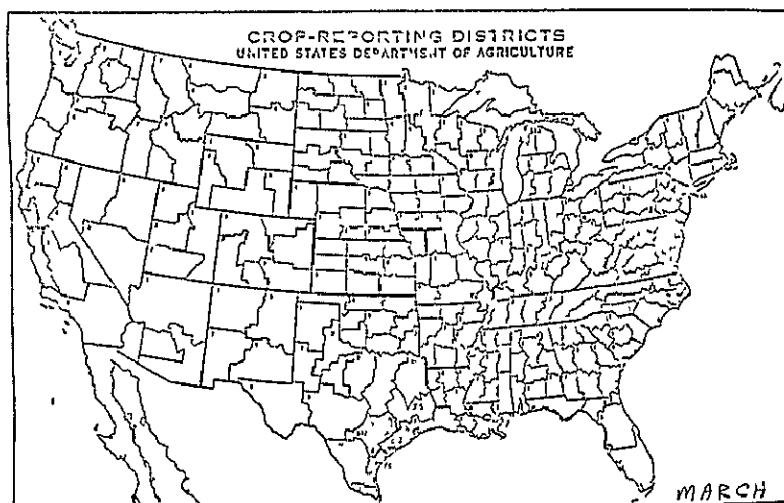
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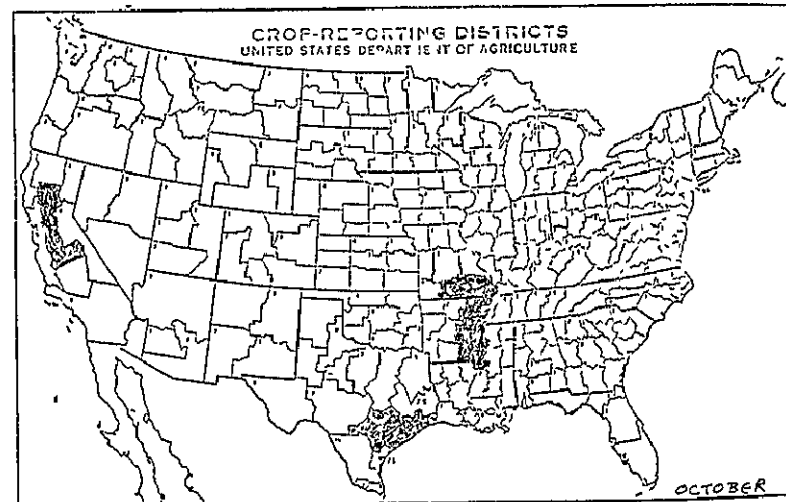
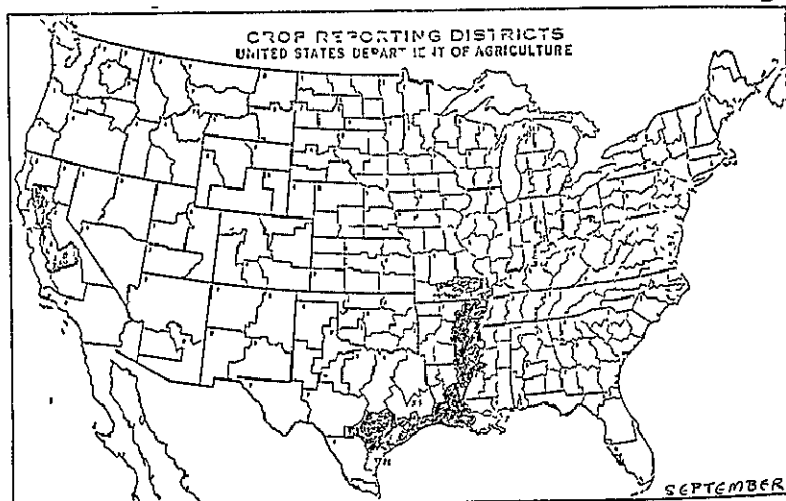
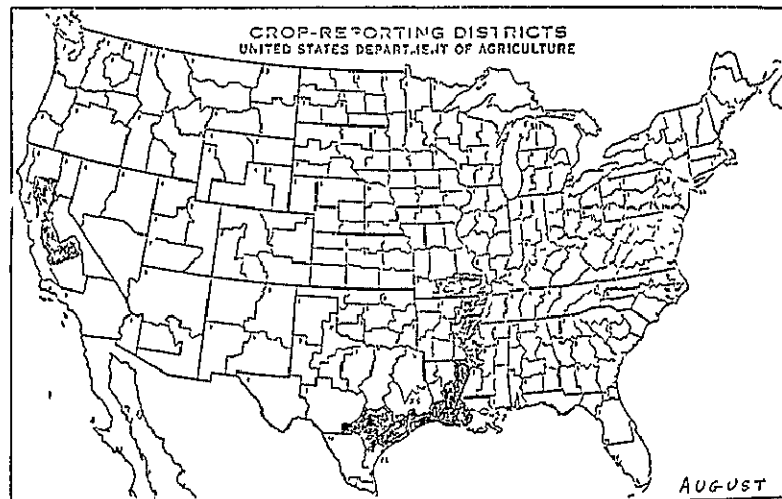
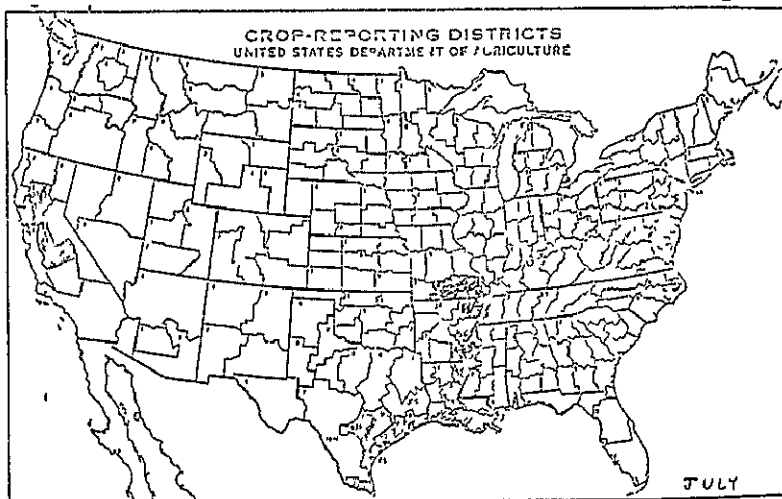
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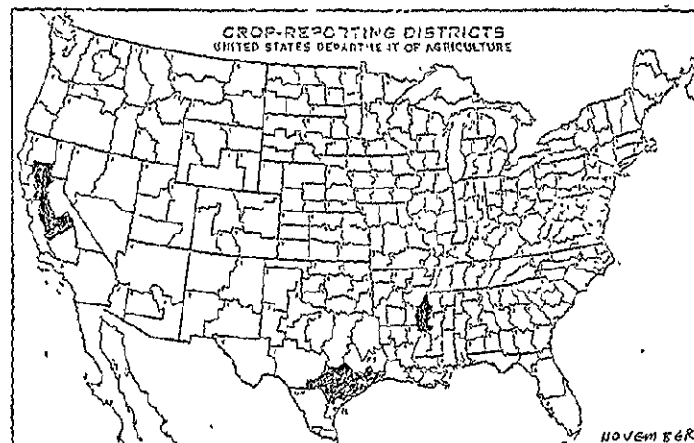



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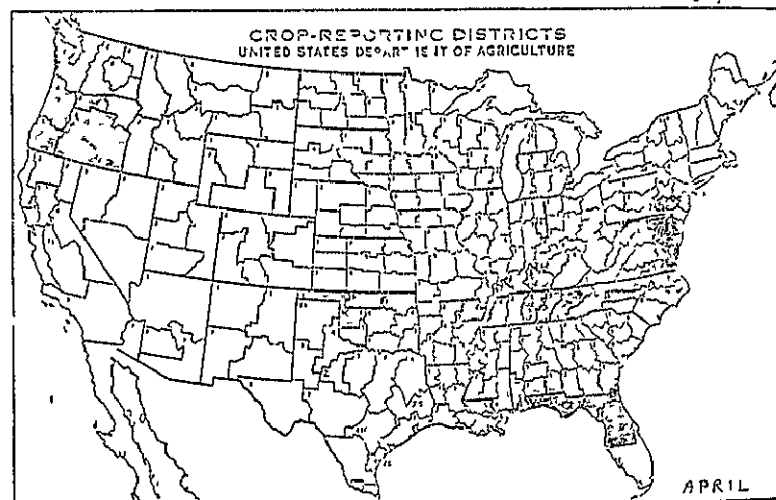
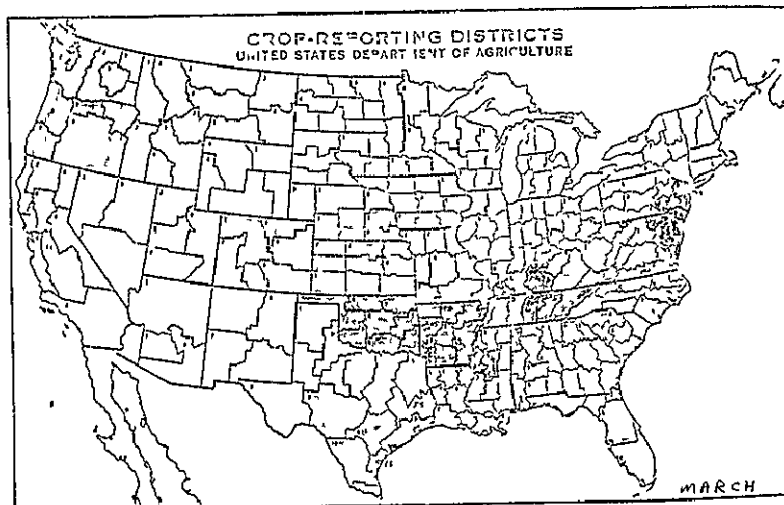
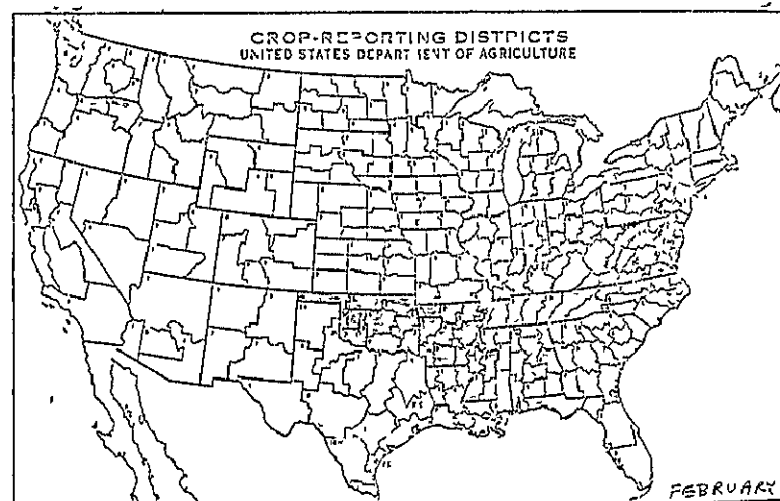
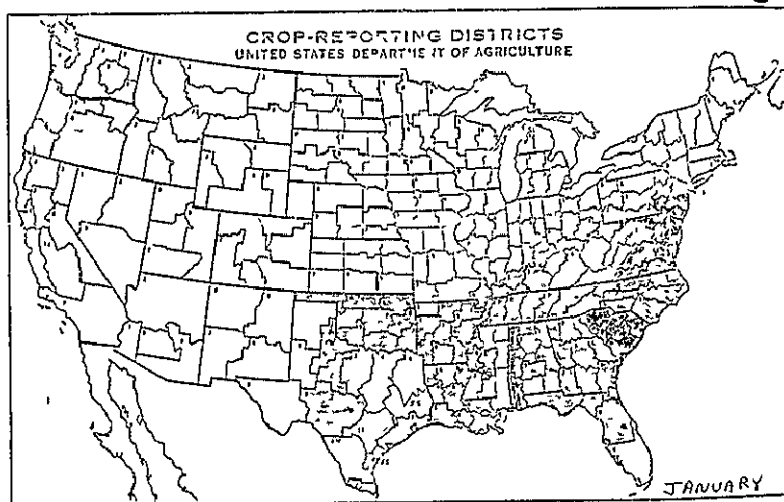
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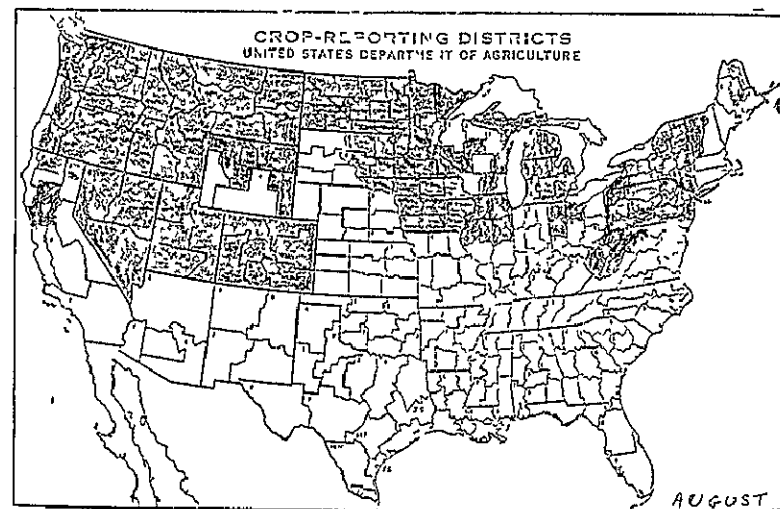
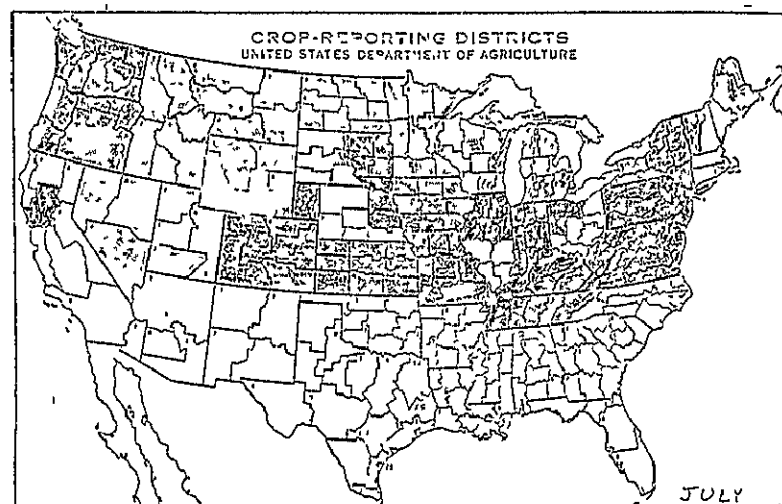
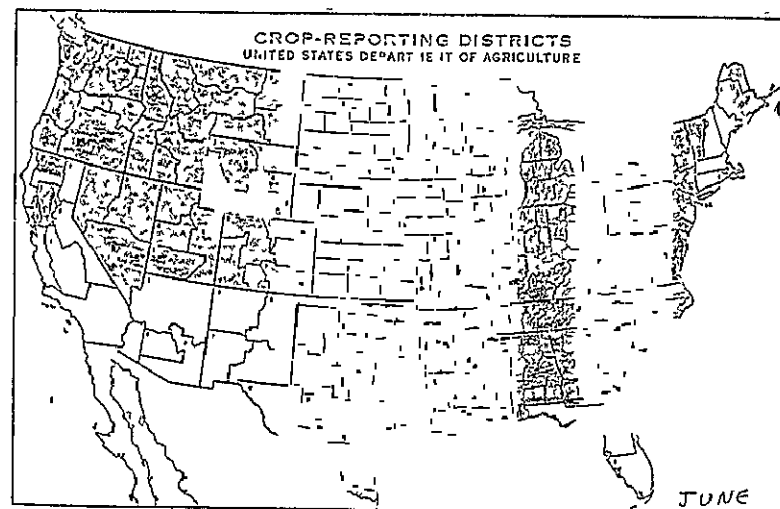
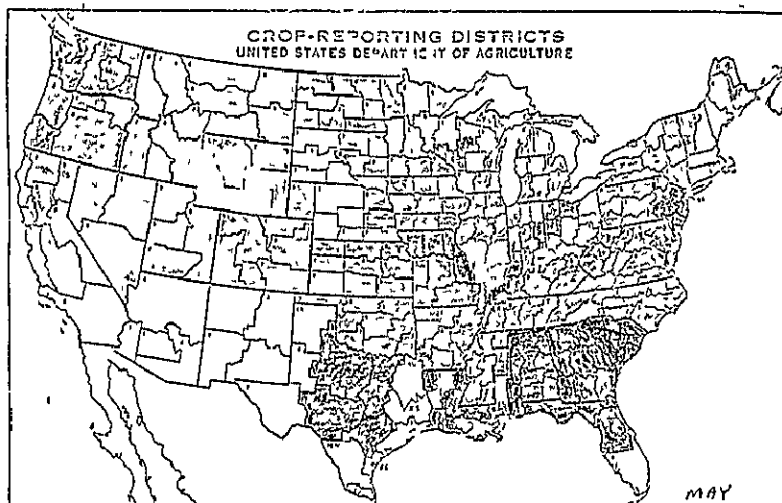
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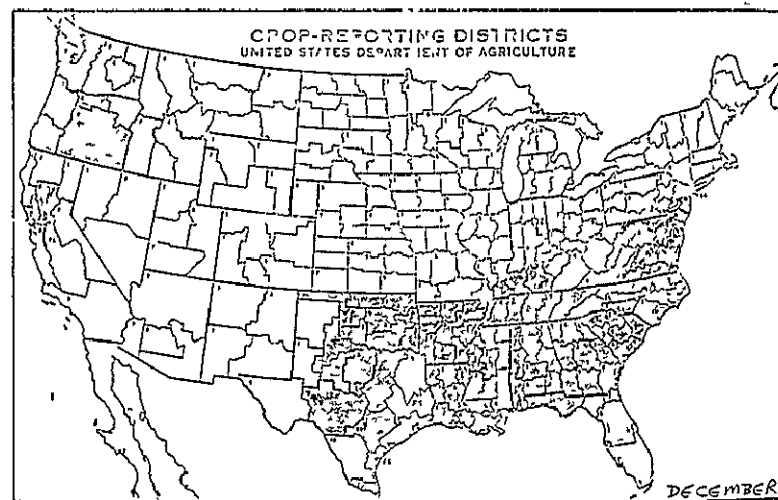
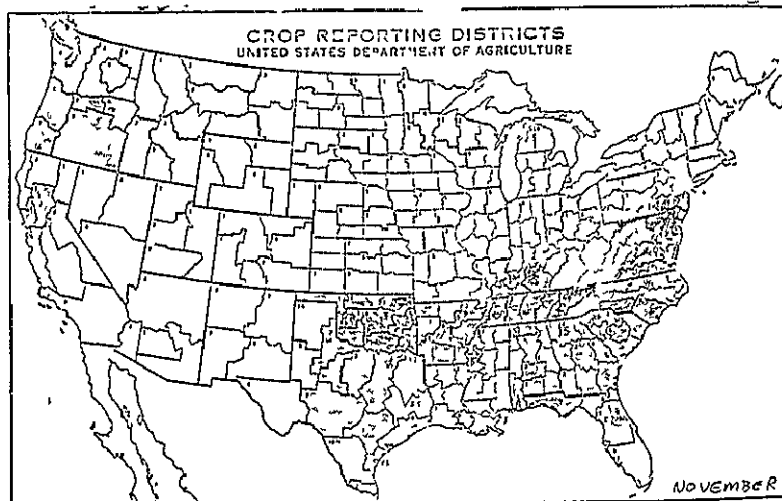
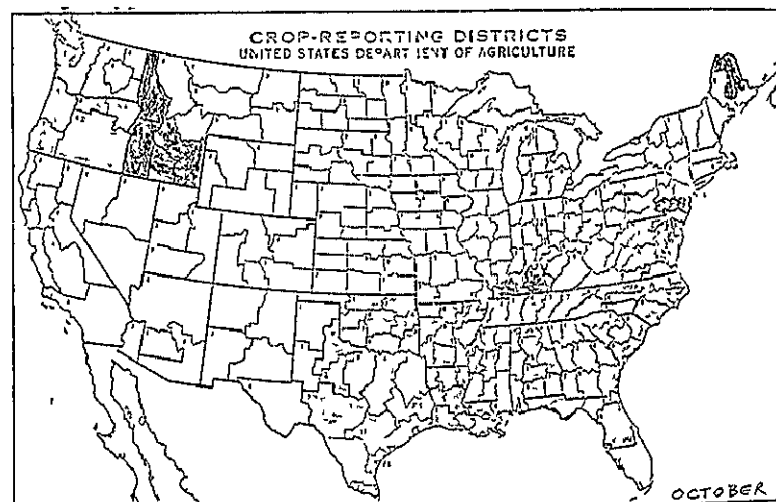
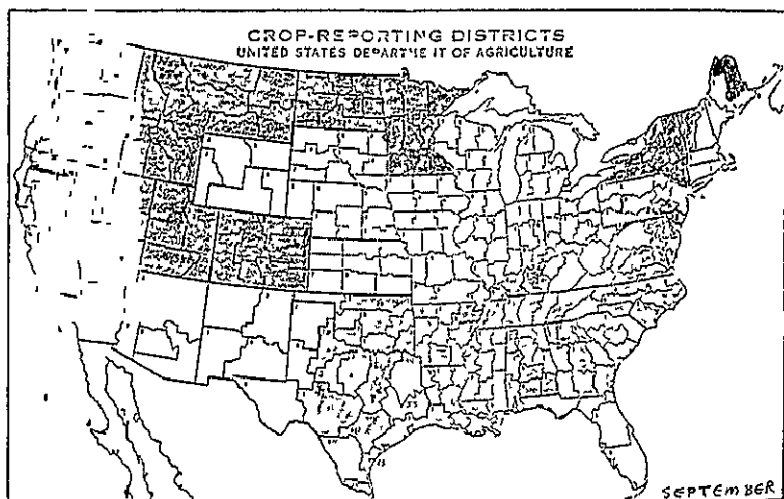
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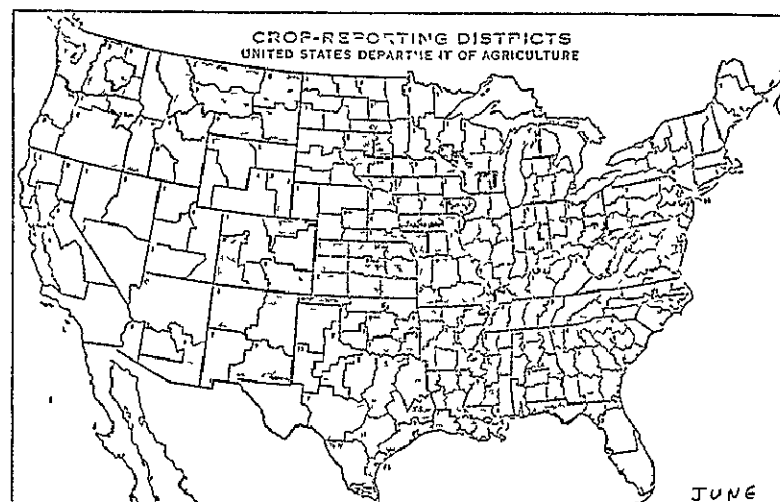
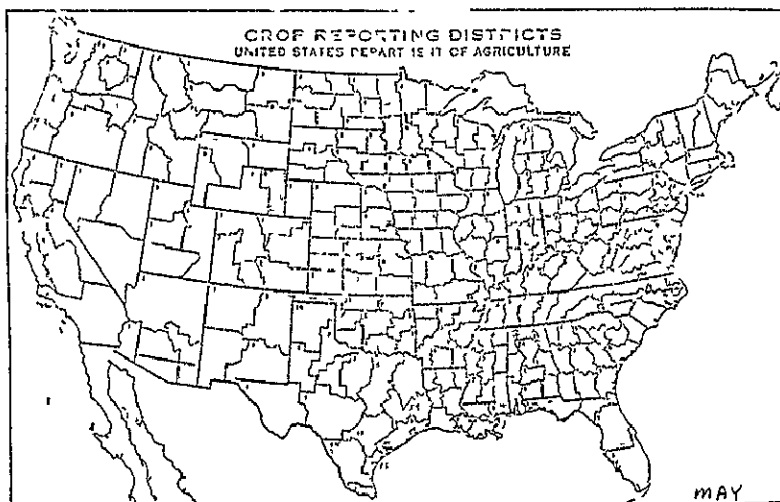
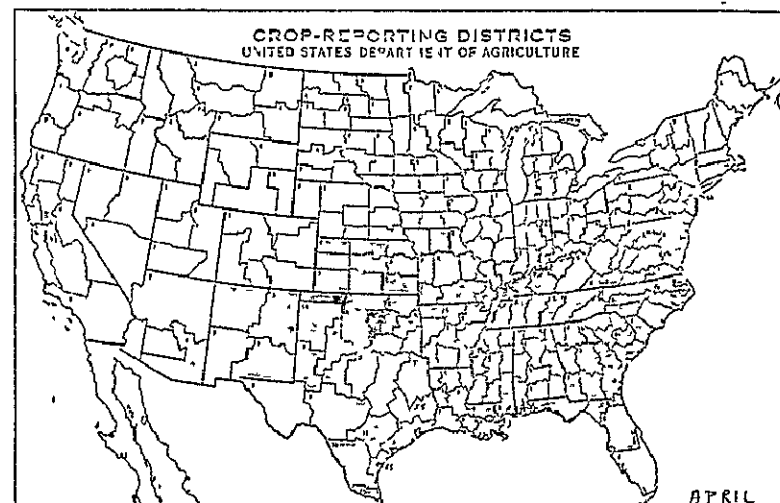
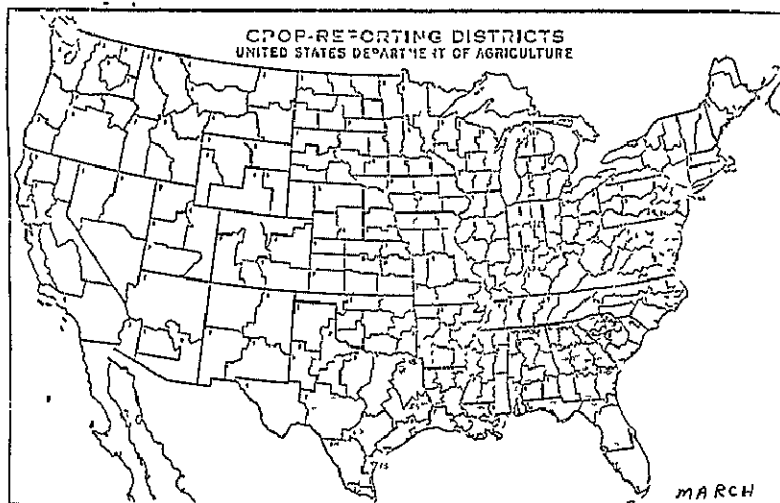
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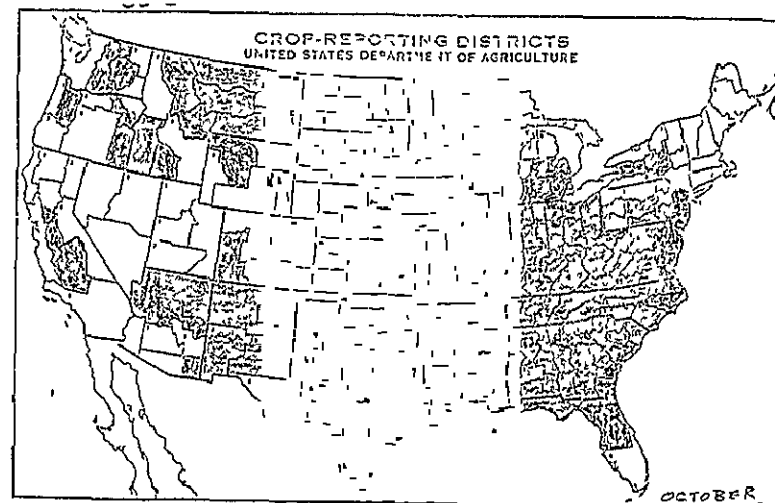
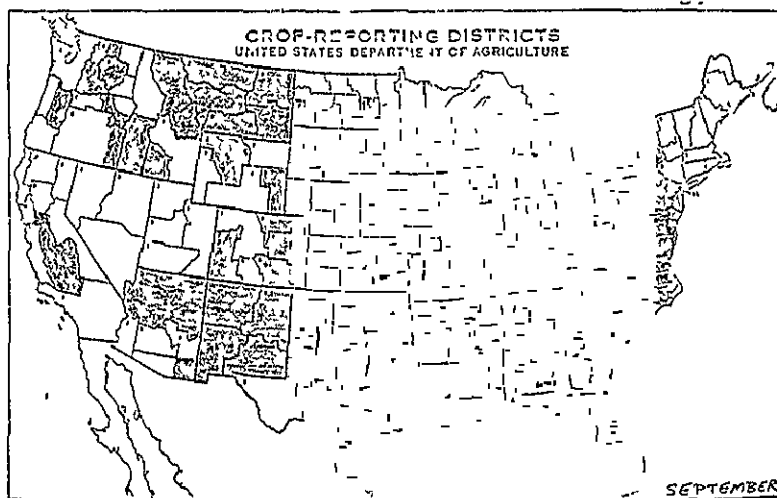
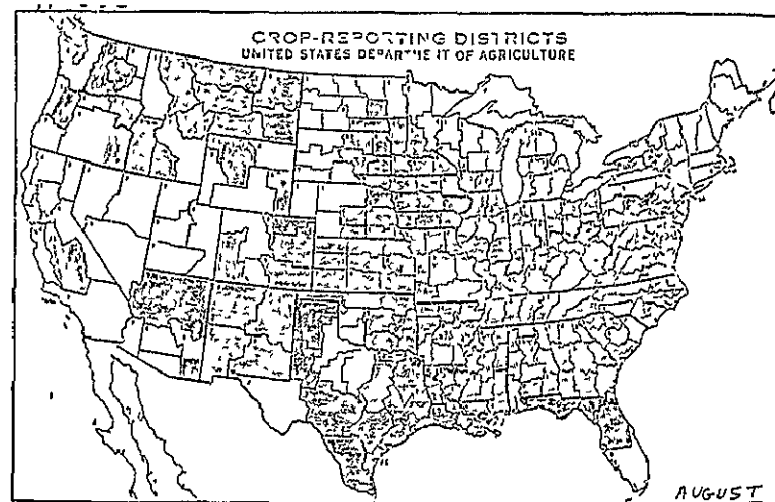
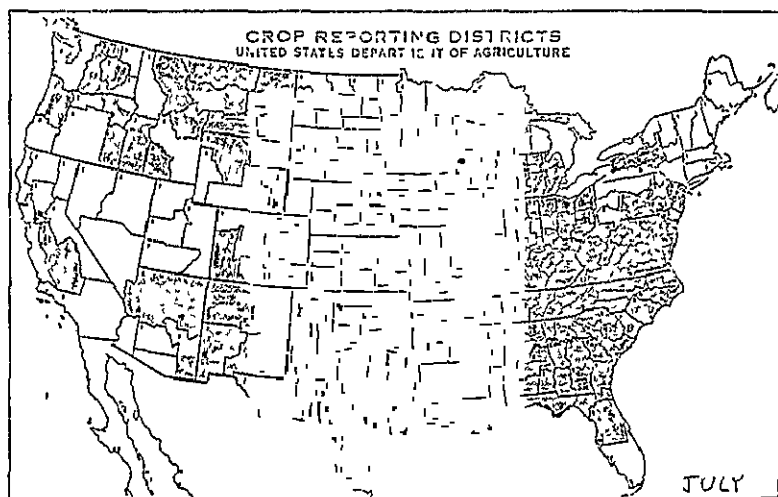


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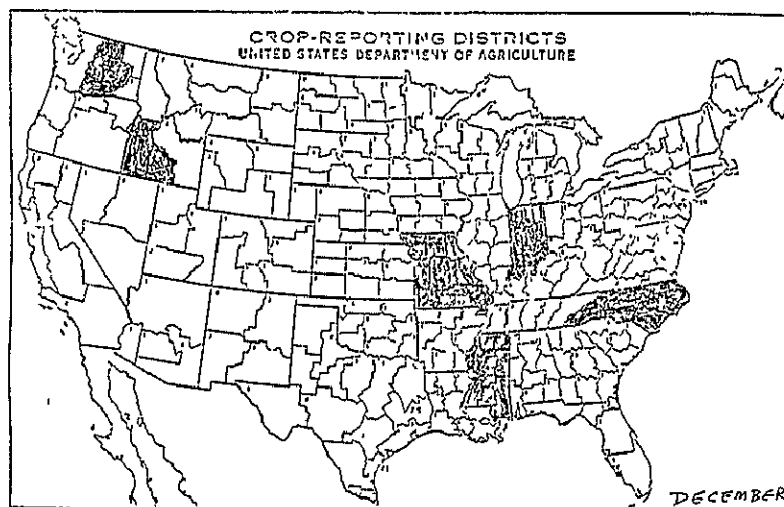
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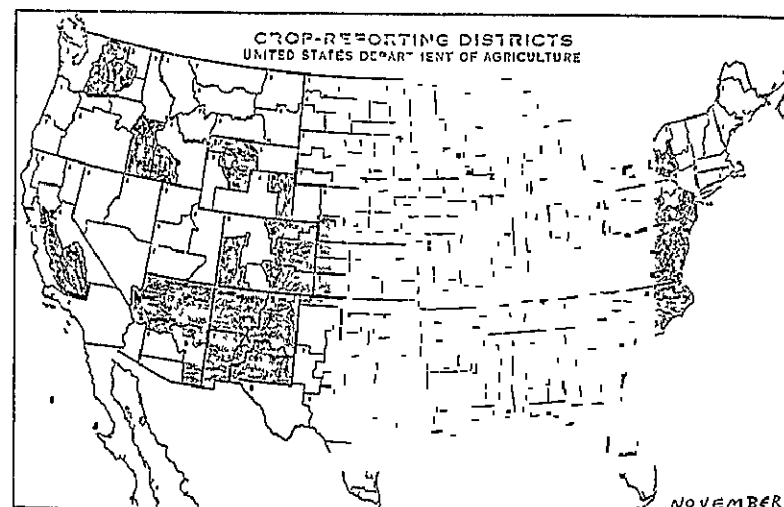
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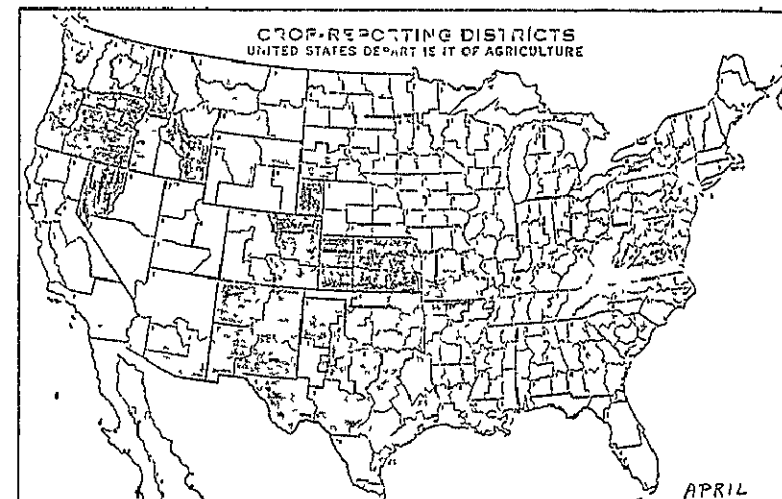
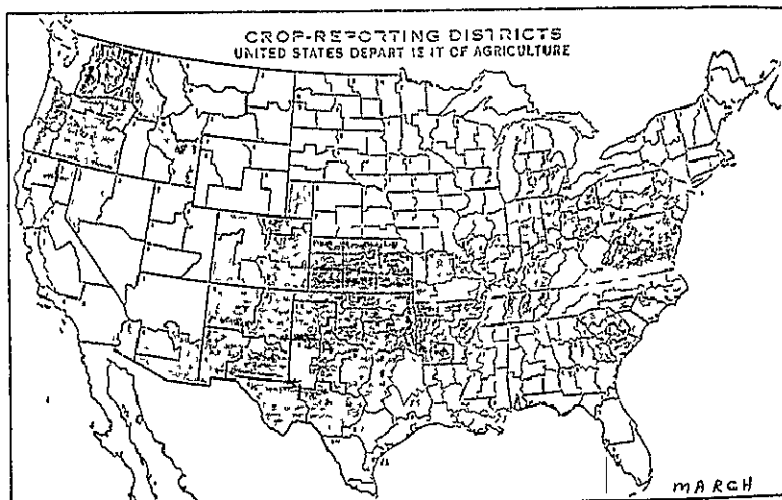
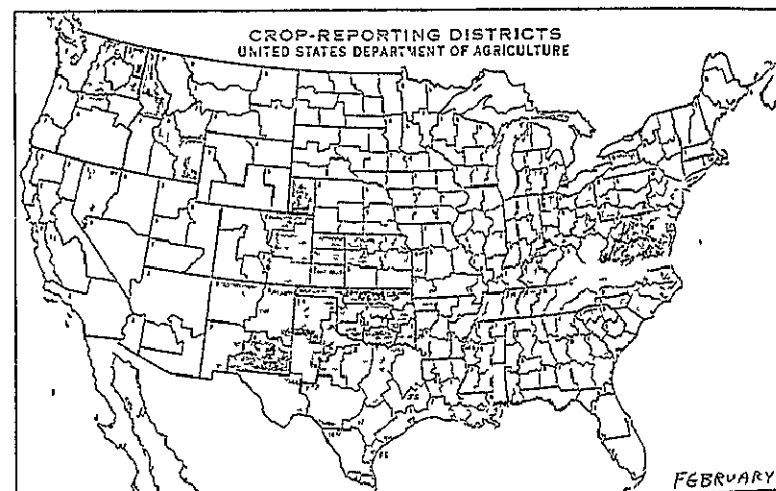
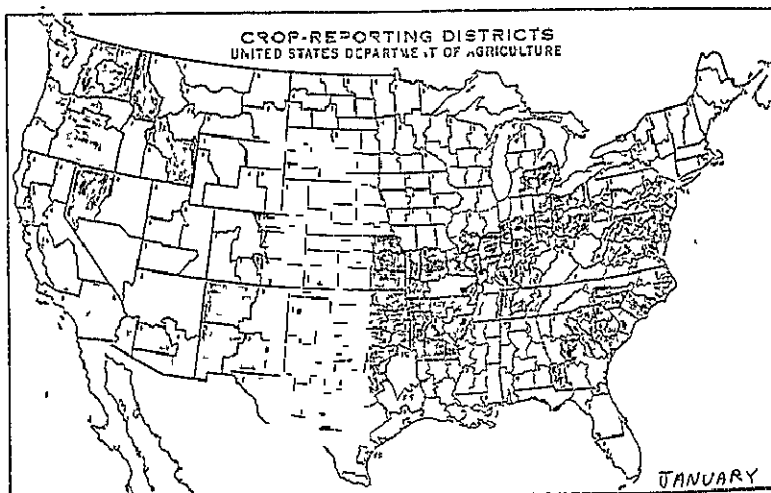
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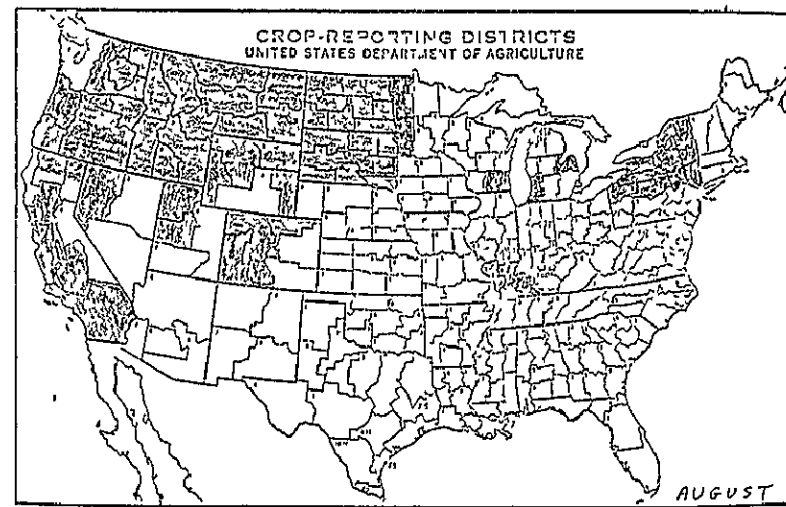
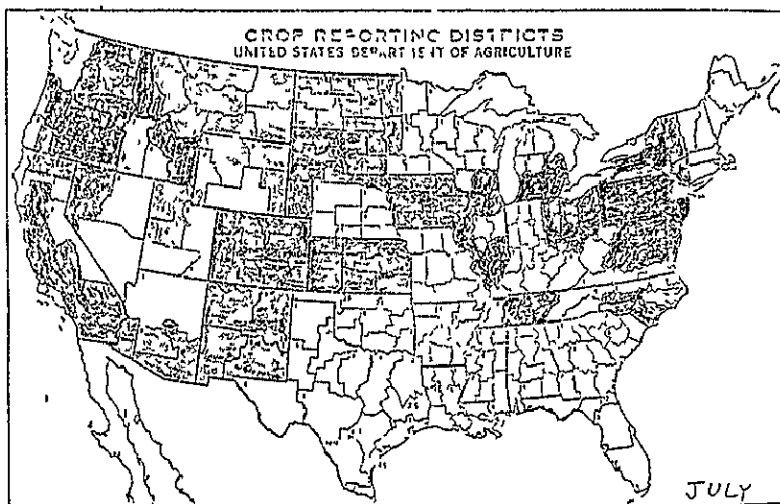
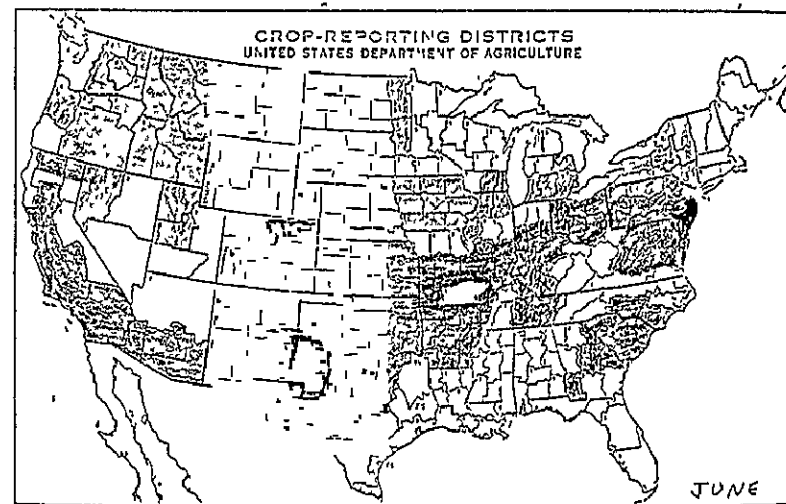
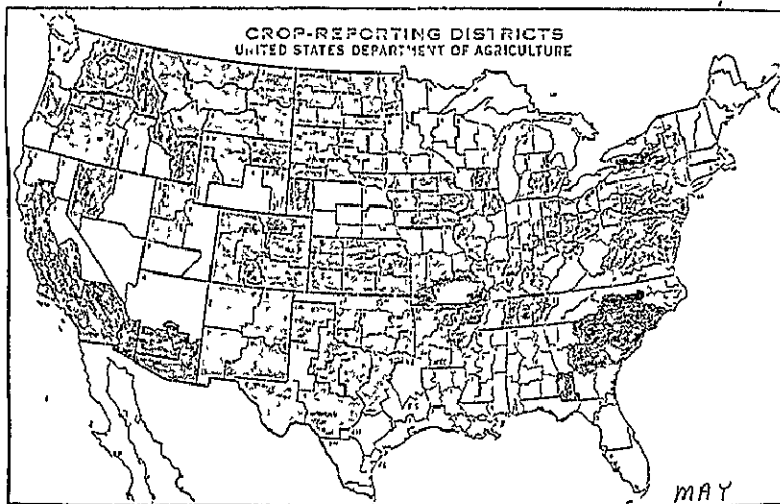
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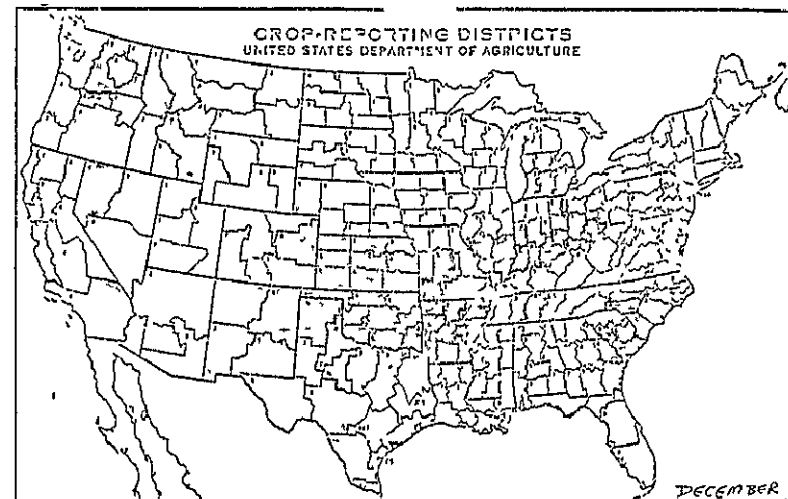
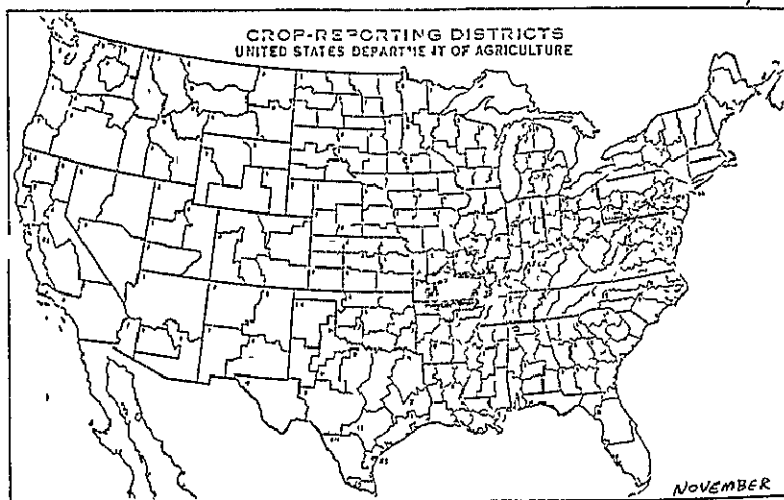
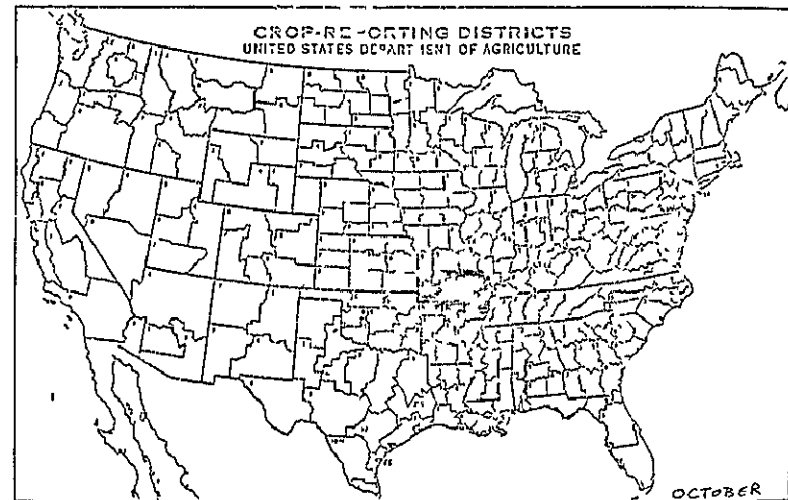
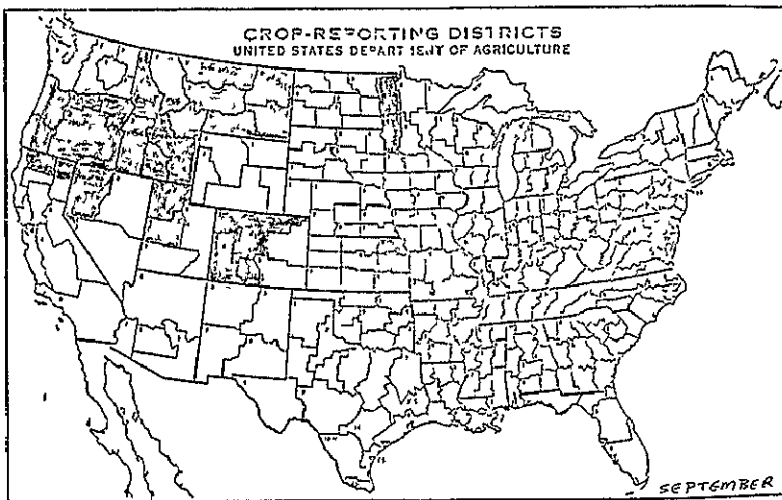
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**BARLEY**

The following tables contain the basic data upon which the preceding maps are based.

Table 16. Spring wheat: Usual planting and harvesting dates, by States and principal producing areas

Wheat type and State	: 1969 :harvested: : acreage : : (000) :	Usual planting dates	Usual harvesting dates			:Principal producing :areas and counties
			: Begin	: Most active	: End	
<u>DURUM</u>	:	:	:	:	:	:
Minnesota	: 80	Apr. 15-May 30	July 25	Aug. 1-Aug. 20	Sept. 10	1, 4
North Dakota	: 2,781	Apr. 15-June 1	Aug. 10	Aug. 15-Sept. 5	Sept. 15	1, 2, 3, 5, 6, 9
South Dakota	: 234	Apr. 1-May 5	July 20	July 25-Aug. 15	Aug. 20	1, 2, 3, 5
Montana	: 230	Apr. 10-May 25	Aug. 5	Aug. 10-Aug. 25	Sept. 20	2, 3
California	: 5	Mar. 15-May 10	Aug. 25	Sept. 1-Sept. 20	Sept. 30	Siskiyou, Modoc
<u>OTHER SPRING</u>	:	:	:	:	:	:
Wisconsin	: 13	Apr. 20-May 5	Aug. 1	Aug. 10-Aug. 20	Aug. 25	9
Minnesota	: 730	Apr. 15-May 30	July 25	Aug. 1-Aug. 20	Sept. 10	1, 4, 5, 7, 8, 9
North Dakota	: 3,905	Apr. 15-May 25	Aug. 5	Aug. 15-Sept. 5	Sept. 10	Statewide
South Dakota	: 1,107	Apr. 1-May 5	July 20	July 25-Aug. 15	Aug. 20	1, 2, 3, 5
Montana	: 1,104	Apr. 10-May 25	Aug. 5	Aug. 10-Aug. 25	Sept. 15	2, 3, 9
Idaho	: 229	Mar. 20-May 25	July 15	Aug. 10-Sept. 5	Sept. 30	Statewide
Wyoming	: 22	Apr. 5-May 20	Aug. 1	Aug. 10-Aug. 25	Sept. 5	1, 2, 3, 5
Colorado	: 35	Mar. 10-Apr. 30	July 5	July 15-Aug. 10	Aug. 30	Statewide
Utah	: 32	Mar. 20-May 1	Aug. 1	Aug. 5-Aug. 25	Sept. 1	1, 5
Nevada	: 6	Apr. 1-May 10	July 25	Aug. 10-Sept. 5	Sept. 15	Humboldt, Pershing, Eureka, Lander
Washington	: 285	Mar. 10-Apr. 10	July 15	July 25-Aug. 20	Sept. 30	2, 3, 5, 9
Oregon	: 56	Feb. 1-Apr. 15	Aug. 1	Aug. 15-Sept. 10	Sept. 15	Statewide except coast

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Table 15. Winter wheat. Usual planting and harvesting dates, by State and principal producing areas

State	1969 Harvested acreage (000)	Usual planting dates	Usual harvesting dates			Principal producing areas and counties
			Begin	Most active	End	
New York	182	Sept. 5-Oct. 10	July 15	July 25-Aug. 10	Aug. 15	4, 5
New Jersey	34	Sept. 20-Nov. 1	July 5	July 15-July 25	Aug. 10	Statewide
Pennsylvania	327	Sept. 1-Oct. 15	July 1	July 15-July 25	Aug. 10	4, 5, 6, 8, 9
Ohio	1,067	Sept. 15-Nov. 5	July 1	July 10-July 25	Aug. 5	Statewide
Indiana	870	Sept. 10-Oct. 30	June 25	June 30-July 20	July 25	Statewide
Illinois	1,273	Sept. 15-Nov. 5	June 25	July 1-July 15	July 20	4, 4A, 5, 6, 6A, 7, 9
Michigan	628	Sept. 15-Oct. 15	July 10	July 20-Aug. 1	Aug. 10	5, 6, 7, 8, 9
Wisconsin	31	Sept. 10-Oct. 10	July 20	July 25-Aug. 5	Aug. 10	Racine, Kenosha, Washington
Minnesota	18	Sept. 1-Sept. 30	July 25	Aug. 1-Aug. 10	Aug. 15	1, 2, 4, 5, 8, 9
Iowa	40	Sept. 10-Oct. 5	July 10	July 15-July 25	Aug. 1	Statewide
Missouri	1,035	Sept. 20-Nov. 1	June 10	June 15-July 1	July 15	Statewide
North Dakota	96	Sept. 5-Oct. 5	Aug. 1	Aug. 10-Aug. 15	Aug. 20	1, 4, 7
South Dakota	622	Sept. 1-Oct. 1	July 10	July 15-Aug. 1	Aug. 10	4, 5, 7, 8
Nebraska	2,780	Aug. 25-Oct. 5	July 1	July 5-July 15	July 30	1, 5, 6, 7, 8, 9
Kansas	9,849	Sept. 10-Oct. 25	June 15	June 20-July 5	July 15	Statewide
Delaware	20	Oct. 5-Nov. 15	June 20	June 25-July 15	July 25	Statewide
Maryland	117	Sept. 25-Nov. 15	June 15	June 20-July 15	Aug. 1	Statewide
Virginia	157	Sept. 20-Dec. 1	June 10	June 20-July 10	July 15	2, 5, 6, 8, 9
West Virginia	14	Sept. 10-Nov. 1	July 10	July 15-Aug. 5	Aug. 10	2, Mason
North Carolina	198	Sept. 15-Nov. 5	June 5	June 15-July 1	July 15	2, 3, 5, 6, 8, 9
South Carolina	82	Oct. 10-Dec. 20	June 1	June 10-July 1	July 10	Statewide
Georgia	86	Sept. 10-Dec. 1	May 20	June 5-June 20	June 25	Statewide
Florida	43	Oct. 15-Dec. 15	May 10	May 15-May 25	June 10	1
Kentucky	183	Sept. 25-Nov. 15	June 15	June 20-July 5	July 15	1, 2, 3, 5
Tennessee	224	Sept. 10-Nov. 30	June 10	June 15-July 5	July 15	Statewide
Alabama	85	Sept. 20-Dec. 1	May 15	June 1-June 20	July 1	Statewide
Mississippi	125	Oct. 1-Nov. 20	May 20	June 5-June 15	June 25	1, 2, 4, 6
Arkansas	301	Sept. 10-Nov. 25	June 1	June 10-June 25	July 5	Statewide
Louisiana	38	Sept. 15-Nov. 15	May 20	June 1-June 15	June 20	3, 5
Oklahoma	4,150	Sept. 5-Oct. 25	June 5	June 10-June 25	June 30	2, 7, 5, 1, 4
Texas	2,869	Sept. 1-Oct. 30	May 20	June 5-June 20	July 5	1N, 1S, 2N, 2S, 3, 4, 7
Montana	2,311	Aug. 25-Oct. 15	July 25	Aug. 1-Aug. 15	Sept. 5	Statewide
Idaho	822	Sept. 1-Oct. 15	July 15	July 25-Aug. 30	Sept. 15	Statewide
Wyoming	220	Aug. 20-Sept. 25	July 20	Aug. 5-Aug. 20	Aug. 25	2, 5
Colorado	2,133	Aug. 20-Oct. 10	June 25	July 10-July 20	Sept. 5	2, 6, 9
New Mexico	159	Sept. 1-Oct. 20	June 5	June 15-July 15	July 20	Statewide
Arizona	73	Oct. 15-Feb. 15	May 20	May 25-June 10	July 15	5, 7, Cochise
Utah	197	Aug. 25-Oct. 20	July 5	July 15-Aug. 5	Aug. 20	Box Elder, Cache, Salt Lake, Utah, Juab, Millard, San Juan
Nevada	5	Sept. 5-Oct. 20	July 15	Aug. 1-Aug. 25	Sept. 5	Humboldt, Pershing
Washington	2,177	Aug. 15-Nov. 20	July 5	July 20-Aug. 15	Sept. 20	2, 3, 5, 9
Oregon	732	Aug. 15-Feb. 1	July 1	July 10-Aug. 15	Sept. 15	Statewide except coast
California	350	Oct. 15-Feb. 15	June 15	July 15-Aug. 15	Aug. 30	5
		Nov. 1-Feb. 15	May 15	June 15-July 15	Aug. 8	5A, 8

Table 12. Soybeans: Usual planting and harvesting dates, by State and principal producing areas

State	1969 harvested: acres (000)	Usual planting dates	Usual harvesting dates			Principal producing areas Statewide, districts or counties
			Begin	Most active	End	
New York	5	May 25-June 25	Oct. 1	Oct. 10-Oct. 20	Oct. 30	4
New Jersey	46	May 25-July 10	Oct. 10	Oct. 25-Nov. 10	Nov. 20	5, 8
Pennsylvania	25	May 10-July 1	Oct. 20	Nov. 1-Nov. 20	Dec. 1	9, Northampton, North- umberland, Montour
Ohio	2,344	May 10-June 20	Sept. 20	Oct. 1-Oct. 25	Nov. 15	1, 2, 4, 5, 7, 8
Indiana	3,311	May 10-June 20	Sept. 20	Sept. 30-Oct. 30	Nov. 5	Statewide
Illinois	6,730	May 5-June 25	Sept. 15	Sept. 25-Oct. 15	Nov. 5	Statewide
Michigan	514	May 10-June 20	Sept. 20	Oct. 10-Oct. 25	Nov. 15	5, 6, 7, 8, 9
Wisconsin	174	May 25-June 15	Oct. 5	Oct. 20-Nov. 1	Nov. 20	4, 8, 9
Minnesota	3,068	May 15-June 15	Sept. 25	Oct. 10-Oct. 25	Nov. 10	1, 4, 5, 7, 8, 9
Iowa	5,450	May 10-June 10	Oct. 1	Oct. 10-Nov. 5	Nov. 15	Statewide
Missouri	3,150	May 1-June 20	Sept. 15	Oct. 1-Oct. 20	Dec. 1	Statewide
North Dakota	185	May 20-June 10	Sept. 25	Oct. 5-Oct. 20	Oct. 25	Cass, Richland, Traill
South Dakota	243	May 15-June 15	Oct. 1	Oct. 10-Oct. 25	Nov. 5	3, 6, 9
Nebraska	766	May 10-June 15	Sept. 20	Oct. 5-Oct. 20	Nov. 5	3, 6, 9
Kansas	852	May 10-July 5	Sept. 20	Oct. 1-Nov. 5	Nov. 20	2, 3, 5, 6, 8, 9
Delaware	162	May 15-July 10	Oct. 5	Oct. 20-Nov. 15	Dec. 1	Statewide
Maryland	205	May 15-July 10	Oct. 1	Oct. 20-Nov. 15	Dec. 1	2, 8, 9
Virginia	361	May 1-July 10	Oct. 1	Oct. 20-Nov. 25	Dec. 5	5, 6, 9
North Carolina	885	May 5-June 25	Oct. 15	Nov. 1-Dec. 1	Dec. 20	3, 6, 9
South Carolina	959	May 1-July 10	Oct. 20	Nov. 1-Dec. 1	Dec. 10	Statewide
Georgia	467	May 1-July 5	Oct. 10	Oct. 20-Nov. 20	Nov. 30	Statewide
Florida	169	May 15-June 15	Sept. 20	Oct. 1-Oct. 31	Nov. 30	1
Kentucky	485	May 5-July 5	Sept. 20	Oct. 1-Nov. 1	Dec. 1	1, 2, 3
Tennessee	1,193	May 1-June 30	Oct. 1	Oct. 15-Nov. 15	Dec. 10	Statewide
Alabama	641	May 5-July 15	Sept. 20	Oct. 1-Oct. 30	Dec. 1	Statewide
Mississippi	2,290	May 1-July 5	Sept. 20	Oct. 15-Nov. 15	Dec. 10	1, 2, 4
Arkansas	4,228	May 1-June 30	Oct. 1	Oct. 15-Nov. 25	Dec. 10	Statewide
Louisiana	1,608	May 1-June 25	Sept. 15	Oct. 1-Nov. 15	Dec. 1	Statewide
Oklahoma	204	May 10-June 30	Sept. 30	Oct. 10-Nov. 15	Nov. 25	3, 6, 9, 8, 5
Texas	262	May 1-July 15	Oct. 1	Oct. 25-Nov. 5	Nov. 30	1N, 1S, 5N, 5S, 9



Table 10 Rye. Usual planting and harvesting dates, by State and principal producing areas

State	1969 harvested acreage (000)	Usual planting dates	Usual harvesting dates			Principal producing areas and counties
			Begin	Most active	End	
New York	18	Aug. 25-Oct 10	July 5	July 15-July 25	Aug. 1	4, 7, 9A
New Jersey	10	Sept. 1-Oct. 15	July 5	July 15-July 25	Aug. 5	Statewide
Pennsylvania	16	Sept.15-Oct 15	July 1	July 15-July 25	Aug. 10	Statewide
Ohio	16	Sept.10-Oct. 20	June 25	July 1-July 15	July 20	Statewide
Indiana	21	Sept.10-Oct. 20	June 15	June 20-July 15	July 20	Statewide
Illinois	25	Aug 20-Sept 25	June 20	June 25-July 5	July 10	Statewide
Michigan	40	Aug. 15-Oct. 15	July 5	July 15-Aug. 1	Aug. 10	Statewide
Wisconsin	18	Sept. 1-Oct 15	July 20	July 25-Aug. 5	Aug. 10	Portage, Waushara
Minnesota	84	Sept 1-Sept.30	July 25	Aug 1-Aug 10	Aug 15	1, 4, 5, 6
Iowa	5	Sept 1-Sept.25	July 1	July 5-July 15	July 20	Statewide
Missouri	16	Aug. 15-Oct. 20	June 10	June 15-June 25	July 5	Statewide
North Dakota	230	Sept. 1-Oct. 1	July 25	Aug. 1-Aug. 15	Aug. 20	Statewide
South Dakota	269	Sept 1-Oct. 1	July 15	July 20-Aug. 5	Aug. 10	2, 3, 5, 6, 8
Nebraska	150	Aug. 15-Sept.25	July 1	July 5-July 20	Aug. 1	1, 3, 7
Kansas	59	Sept. 1-Oct 1	June 5	June 10-June 25	July 1	Statewide
Delaware	8	Sept.15-Nov. 15	June 20	June 25-July 15	July 20	Statewide
Maryland	15	Sept.10-Nov. 15	June 15	June 20-July 15	July 25	Statewide
Virginia	19	Sept. 1-Dec. 1	June 1	June 15-July 1	July 5	6, 9
North Carolina	16	Aug. 20-Nov. 15	June 5	June 15-July 5	July 10	2, 5, 8, 9
South Carolina	21	Sept. 1-Dec. 5	May 25	June 1-June 15	June 20	Statewide
Georgia	72	Sept. 1-Nov. 15	May 10	May 25-June 10	June 20	Statewide
Kentucky	7	Sept.10-Oct. 15	June 15	June 25-July 10	July 15	2, 5
Tennessee	6	Aug. 15-Nov. 1	June 1	June 10-July 1	July 5	3, 4, 5
Oklahoma	49	Sept 5-Oct. 15	June 5	June 10-June 25	June 30	5, 4, 2, 7, 8
Texas	38	Sept. 1-Oct. 30	May 15	June 5-June 20	July 1	1N, 1S, 2N, 2S, 3, 4
Montana	7	Aug. 20-Oct. 10	July 20	July 25-Aug. 15	Sept. 1	2, 3
Idaho	7	Sept.15-Sept.30	July 10	July 20-July 30	Aug. 5	Statewide
Wyoming	15	Aug. 20-Sept.25	July 20	Aug. 1-Aug. 15	Aug. 25	Statewide
Colorado	38	Aug. 25-Oct. 15	July 1	July 10-July 30	Aug. 15	2, 6, 9
Washington	36	Aug. 10-Nov. 1	July 5	July 20-Aug. 15	Sept. 1	2, 5
Oregon	15	Sept. 1-Feb. 1	July 10	July 15-Aug. 20	Sept. 1	Statewide except coast

Table 9. Rice. Usual planting and harvesting dates, by State and principal producing areas

State	: 1969 :harvested : acreage : (000)	Usual planting dates	Usual harvesting dates			: Principal producing : areas and counties
			: Begin	: Most active	: End	
Missouri	: 5.4	May 1-May 20	Oct. 1	Oct. 5-Oct. 25	Nov. 1	8, 9
Mississippi	: 60	Apr.15-May 31	Sept. 15	Oct. 1-Oct. 15	Nov. 15	1, 4
Arkansas	: 515	Apr.10-May 25	Sept. 10	Sept.25-Oct.20	Nov. 5	3, 6, 9
Louisiana	: 611	Apr. 1-May 15	Aug. 1	Aug.15-Sept.15	Oct. 1	3, 5, 7, 8
Texas	: 548	Mar. 20-June 5	July 30	Aug. 20-Sept. 1	Nov. 10	8N, 9
California	: 389	Apr. 1-June 1	Sept. 15	Oct.10-Oct. 30	Nov. 30	5, Fresno

Table 7. Oats: Usual planting and harvesting dates, by State and principal producing areas Con.

State and sowing season	1969 harvested acreage (000)	Usual planting dates	Usual harvesting dates			Principal producing areas and counties
			Begin	Most active	End	
Maine	34	May 10-June 10	Aug. 20	Sept. 5-Oct. 1	Oct. 15	Aroostook, Penobscot
Vermont	6	Apr. 25-June 5	Aug. 1	Aug. 10-Aug. 25	Sept. 5	Statewide
New York	365	Apr. 20-May 30	Aug. 1	Aug. 10-Aug. 25	Sept. 10	Statewide
New Jersey						
Fall sown	10	Sept. 20-Oct. 20	July 15	July 20-Aug. 10	Aug. 20	5, 8
Spring sown		Mar. 15-Apr. 25	July 15	July 20-Aug. 10	Aug. 20	2
Pennsylvania						
Fall sown	444	Sept. 1-Sept. 20	July 10	July 20-Aug. 1	Aug. 10	9
Spring sown		Apr. 10-May 25	July 20	Aug. 1-Aug. 20	Sept. 1	Statewide
Ohio	560	Apr. 1-May 10	July 15	July 20-Aug. 5	Aug. 15	1, 2, 4
Indiana	320	Apr. 1-Apr. 30	July 5	July 10-July 30	Aug. 5	Statewide
Illinois	703	Mar. 25-May 1	July 10	July 15-Aug. 1	Aug. 15	1, 3, 4, 5, 6
Michigan	458	Apr. 15-May 30	July 20	July 25-Aug. 20	Aug. 30	Statewide
Wisconsin	1,687	Apr. 15-May 5	July 25	Aug. 5-Aug. 15	Aug. 25	4, 6, 8, Marathon
Minnesota	3,388	Apr. 10-May 25	July 25	Aug. 1-Aug. 20	Sept. 10	Statewide
Iowa	1,840	Apr. 5 - May 1	July 15	July 20-Aug. 1	Aug. 15	Statewide
Missouri	170	Mar. 1-Apr. 25	June 15	June 25-July 10	July 20	Statewide
North Dakota	2,511	Apr. 15-June 1	Aug. 5	Aug. 15-Sept. 1	Sept. 5	Statewide
South Dakota	2,357	Apr. 5 -May 15	July 15	July 20-Aug. 10	Aug. 15	2, 3, 5, 6, 9
Nebraska	561	Mar. 20-May 1	July 1	July 5-July 15	July 25	1, 3, 6
Kansas	160	Feb. 25-May 1	June 25	June 30-July 10	July 20	Statewide
Delaware	3	Sept. 20-Nov. 10	June 15	June 25-July 10	July 20	Statewide
Maryland						
Fall sown	28	Sept. 15-Nov. 10	June 15	June 25-July 10	July 25	Statewide
Spring sown		Mar. 20-May 1	June 25	July 5-July 25	Aug. 5	Statewide
Virginia						
Fall sown	49	Sept. 5-Oct. 25	June 1	June 10-July 1	July 10	5, 6, 8, 9
Spring sown		Feb. 1-Apr. 15	June 15	July 1-July 15	July 20	2, 4, 7, 8
West Virginia	12	Apr. 10-May 10	July 15	July 15-Aug. 10	Aug. 20	Statewide
North Carolina	120	Sept. 15-Nov. 1	May 25	June 10-June 25	July 5	2, 5, 8, 9
South Carolina						
Fall sown	83	Oct. 1-Dec. 10	May 20	May 20-June 10	June 20	Statewide
Spring sown		Jan. 10-Mar. 1	June 1	June 10-June 20	July 1	Statewide
Georgia	94	Sept. 10-Dec. 1	May 10	June 1-June 10	June 25	Statewide

Table 7. Oats: Usual planting and harvesting dates, by State and principal producing areas -- Con.

State and sowing season	1969 harvested: acreage (000)	Usual planting dates	Usual harvesting dates			Principal producing areas and counties
			Begin	Most active	End	
Florida	11	Oct. 1-Nov. 30	Apr. 15	May 1-May 15	May 30	1, 3, 5
Kentucky						
Fall sown	19	Aug. 25-Oct. 1	June 15	June 20-July 5	July 15	1, 2, 3
Spring sown		Mar. 1-Apr. 15	June 25	June 1-July 15	July 25	3, 5, 6
Tennessee						
Fall sown	43	Sept. 1-Nov. 1	June 1	June 15-July 5	July 10	Statewide
Spring sown		Mar. 15-Apr. 15	Mostly for hay			4, 5, 6
Alabama	29	Sept. 20-Dec. 1	May 15	June 1-June 20	July 1	Statewide
Mississippi						
Fall sown	50	Oct. 1-Nov. 15	May 25	June 5-June 15	June 25	1, 4, 5
Spring sown		Feb. 15-Mar. 15	June 1	June 10-June 20	June 30	Statewide
Arkansas						
Fall sown	68	Sept. 15-Nov. 15	June 1	June 5-June 15	June 25	Statewide
Spring sown		Feb. 20-Mar. 20	June 10	June 15-July 1	July 5	Statewide
Louisiana	28	Sept. 15-Nov. 15	May 10	May 20-June 10	June 15	1, 3, 5, 6, 7
Oklahoma						
Fall sown	158	Sept. 15-Oct. 30	June 1	June 10-June 20	June 30	Statewide
Spring sown		Jan. 30-Mar. 25	June 1	June 10-June 20	June 30	Statewide
Texas	670	Sept. 5-Nov. 20	May 15	June 1-June 15	June 20	2n, 2s, 3, 4, 7, 8n
Montana	291	Apr. 10-June 5	Aug. 5	Aug. 10-Sept. 1	Sept. 15	Statewide
Idaho	100	Mar. 25-May 25	Aug. 1	Aug. 10-Sept. 20	Oct. 10	Statewide
Wyoming	94	Apr. 5-May 20	Aug. 5	Aug. 10-Aug. 25	Sept. 1	1, 2, 5
Colorado	93	Mar. 20-May 5	July 15	July 25-Aug. 30	Sept. 20	Statewide
Utah	22	Mar. 20-May 15	Aug. 1	Aug. 10-Aug. 30	Sept. 20	Statewide
Nevada	3	Apr. 1-May 25	July 25	Aug. 5-Sept. 1	Sept. 10	Statewide
Washington	80	Mar. 10-Apr. 10	July 15	Aug. 1-Aug. 25	Sept. 10	Statewide
Oregon						
Fall sown	113	Oct. 1-Feb. 15	July 10	July 25-Aug. 15	Sept. 1	Statewide )except
Spring sown		Feb. 15-Apr. 15	Aug. 10	Aug. 20-Sept. 10	Sept. 20	Statewide )coast
California						
Fall sown	95	Nov. 1-Mar. 1	July 1	July 15-July 30	Aug. 15	Sonoma, Butte, Sutter, Solano, Sacramento
Spring sown		Mar. 1-May 10	Aug. 25	Sept. 1-Sept. 20	Sept. 30	Modoc, Siskiyou
Alaska	1.5	May 1-July 1	Aug. 20	Sept. 10-Sept. 30	Oct. 15	Tanana & Matanuska Valleys

Table 2. Corn for Grain: Usual planting and harvesting dates, by State and principal producing areas

State	1969 harvested acreage (000)	Usual planting dates	Usual harvesting dates			Principal producing areas and counties
			Begin	Most active	End	
New York	247	May 10-June 15	Oct. 10	Oct. 20-Nov. 15	Dec. 1	4, 5
New Jersey	61	May 10-June 20	Oct. 5	Oct. 20-Nov. 10	Nov. 25	Statewide
Pennsylvania	907	May 1-June 20	Sept. 20	Oct. 1-Oct. 20	Nov. 10	5, 8, 9
Ohio	2,740	May 1-June 15	Sept. 25	Oct. 10-Nov. 5	Nov. 25	Statewide
Indiana	4,742	May 1-June 10	Sept. 30	Oct. 10-Nov. 30	Dec. 10	Statewide
Illinois	9,698	May 1-June 15	Oct. 1	Oct. 15-Nov. 15	Dec. 5	Statewide
Michigan	1,266	May 1-June 15	Oct. 1	Oct. 15-Nov. 15	Dec. 1	5, 6, 7, 8, 9
Wisconsin	1,684	May 5-June 10	Oct. 10	Oct. 20-Nov. 10	Nov. 25	4, 7, 8, Dane, Rock, Grant
Minnesota	4,139	May 1-June 15	Oct. 5	Oct. 20-Nov. 15	Nov. 30	4, 5, 6, 7, 8, 9
Iowa	9,514	May 1-June 1	Oct. 5	Oct. 25-Nov. 25	Dec. 5	Statewide
Missouri	2,603	Apr. 20-June 1	Sept. 15	Oct. 10-Nov. 15	Dec. 20	Statewide
North Dakota	123	May 15-June 20	Oct. 5	Oct. 10-Oct. 25	Nov. 5	6, 9
South Dakota	2,447	May 5-June 5	Oct. 1	Oct. 20-Nov. 5	Nov. 20	2, 3, 5, 6, 9
Nebraska	4,620	Apr. 25-June 5	Sept. 25	Oct. 15-Nov. 10	Dec. 5	3, 5, 6, 8, 9
Kansas	1,236	Apr. 15-June 10	Sept. 15	Oct. 10-Nov. 15	Dec. 5	Statewide
Delaware	170	May 1-June 15	Sept. 5	Sept. 15-Oct. 20	Nov. 15	Statewide
Maryland	479	May 1-June 15	Sept. 1	Sept. 15-Oct. 25	Nov. 20	Statewide
Virginia	432	Apr. 15-June 25	Sept. 1	Oct. 1-Nov. 10	Dec. 1	Statewide
West Virginia	49	May 1-June 5	Sept. 10	Sept. 15-Oct. 15	Nov. 1	Statewide
North Carolina	1,281	Apr. 1-June 10	Aug. 25	Oct. 1-Nov. 10	Jan. 1	Statewide
South Carolina	402	Mar. 20-May 20	Sept. 1	Oct. 1-Nov. 10	Dec. 1	Statewide
Georgia	1,426	Mar. 20-May 15	Sept. 1	Oct. 1-Nov. 1	Dec. 1	Statewide
Florida	358	Mar. 1-Apr. 30	Aug. 15	Sept. 1-Sept. 30	Nov. 15	1, 3, 5
Kentucky	998	Apr. 20-June 15	Sept. 20	Oct. 5-Nov. 5	Nov. 25	Statewide
Tennessee	605	Apr. 15-June 15	Sept. 10	Oct. 15-Nov. 5	Dec. 5	Statewide
Alabama	619	Mar. 20-June 5	Aug. 20	Sept. 15-Nov. 15	Dec. 5	Statewide
Mississippi	318	Apr. 1-May 31	Sept. 1	Oct. 15-Nov. 15	Dec. 10	Statewide
Arkansas	47	Apr. 10-May 30	Sept. 10	Oct. 1-Nov. 10	Dec. 1	Statewide
Louisiana	134	Mar. 1-May 15	Aug. 1	Sept. 1-Oct. 1	Oct. 15	Statewide
Oklahoma	58	Apr. 5-May 25	Sept. 1	Sept. 10-Oct. 15	Nov. 10	1, 3, 5, 6, 8, 9
Texas	571	Mar. 1-May 30	July 20	Sept. 25-Oct. 10	Nov. 1	1N, 1S, 4, 5N, 5S, 7, 8N, 9, 10N, 10S
Montana	6	May 10-June 10	Sept. 15	Sept. 20-Oct. 5	Oct. 15	Statewide
Idaho	28	May 1-May 25	Oct. 10	Oct. 5-Nov. 15	Dec. 10	7, 8
Wyoming	18	May 10-June 15	Oct. 15	Nov. -Nov. 15	Dec. 1	1, 5
Colorado	302	Apr. 25-June 1	Oct. 1	Oct. 10-Nov. 20	Dec. 1	2, 6, 7, 9
New Mexico	17	Apr. 15-June 8	Sept. 10	Oct. 10-Nov. 1	Dec. 1	Statewide
Arizona	16	Apr. 15-June 1	Aug. 15	Oct. 1-Oct. 25	Nov. 10	2 Cochise
Washington	33	May 1-June 5	Oct. 15	Oct. 25-Nov. 20	Dec. 15	2, 5,
Oregon	10	May 5-June 10	Sept. 15	Sept. 25-Oct. 10	Oct. 20	1 except coast, Umatilla, Malheur, Douglas, Baker
California	194	Apr. 15-July 1	Sept. 15	Oct. 1-Nov. 10	Nov. 30	5A, Sacramento, Yolo

Table 1 Barley. Usual planting and harvesting dates, by State and principal producing areas--Con.

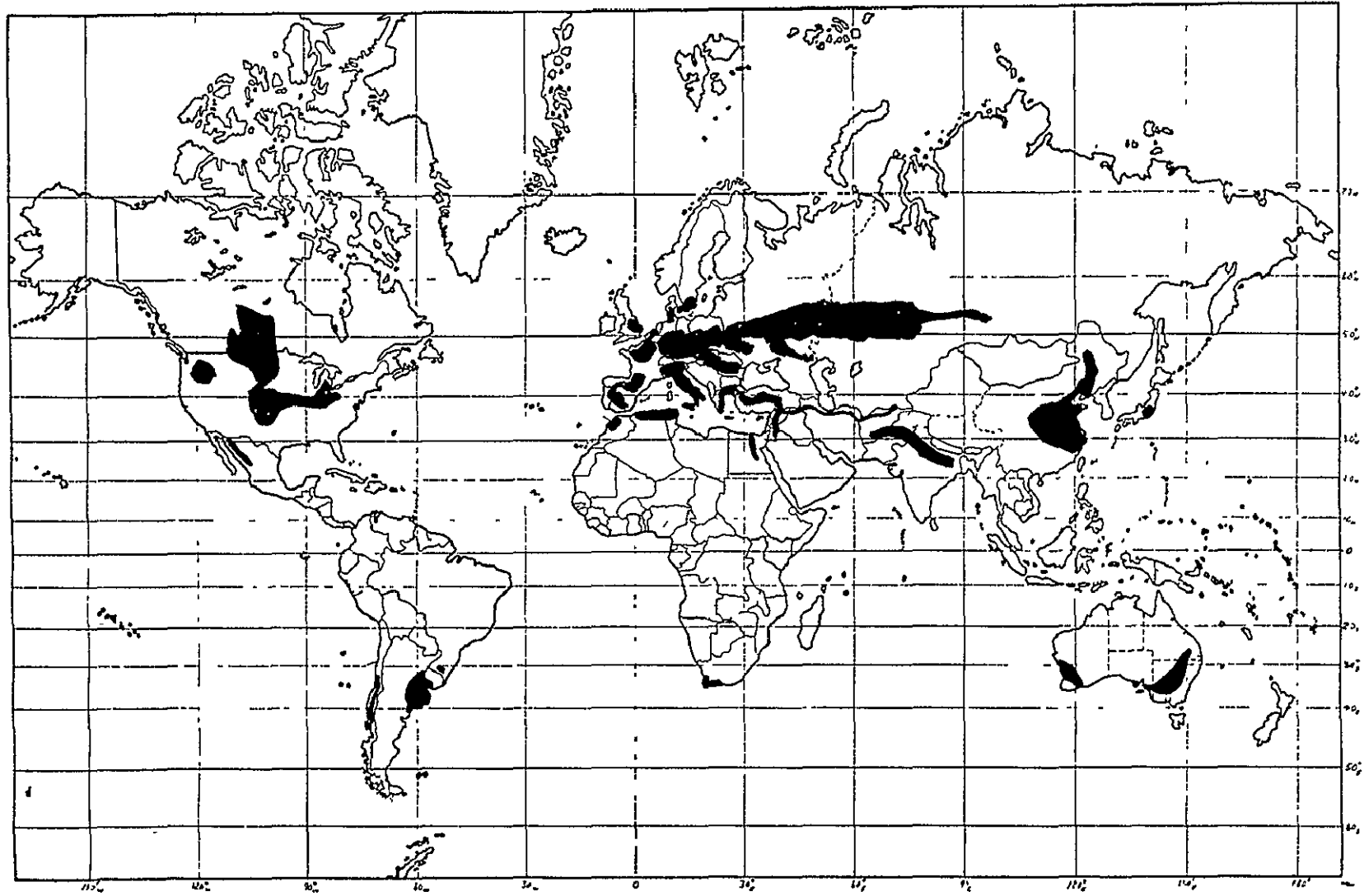
State and sowing season	1969 harvested acreage (000)	Usual planting dates	Usual harvesting dates			Principal producing areas and counties
			Begin	Most active	End	
Arkansas	2	Sept 10-Nov 1	June 1	June 10-June 25	July 5	Statewide
Oklahoma						
Fall sown	422	Sept 10-Oct 30	June 5	June 10-June 20	June 30	Statewide
Spring sown		Jan. 30-Mar. 15	June 5	June 10-June 20	June 30	Statewide
Texas	94	Sept 20-Oct. 30	May 25	June 5-June 15	June 20	1N, 2N, 2S, 3, 4, 6, 7
Montana	1,617	Apr. 10-May 30	Aug 5	Aug 10-Aug. 25	Sept. 15	Statewide
Idaho						
Fall sown	584	Sept 1-Oct. 15	July 15	July 25-Aug 20	Sept. 1	1-7
Spring sown		Mar. 25-May 25	July 25	Aug 5-Sept 15	Sept 30	Statewide
Wyoming	116	Apr. 5-May 20	Aug. 1	Aug. 5-Aug. 20	Sept 1	1, 2, 3, 5
Colorado						
Fall sown	289	Sept 1-Oct. 15	June 20	July 1-July 20	Aug 5	2, 6, 9
Spring sown		Mar. 15-Apr. 30	June 30	July 5-Sept 10	Sept 20	1, 2, 7, 8
New Mexico						
Fall sown	14	Sept. 15-Nov 1	June 10	June 15-July 10	July 20	Statewide
Spring sown		Feb. 15-Apr. 1	June 15	June 20-July 15	Aug 1	9
Arizona	144	Oct 1-Feb 15	May 20	May 25-June 30	July 10	5, 7, 9
Utah	128	Mar 20-Apr. 25	Aug. 1	Aug. 20-Sept 1	Sept. 10	1, 5
Nevada						
Fall sown	19	Sept 5-Oct 20	July 10	July 15-Aug 25	Sept 5	1
Spring sown		Apr 5-May 10	July 20	July 25-Sept 1	Sept. 15	1
Washington						
Fall sown	370	Sept. 1-Nov. 10	July 1	July 15-Aug. 10	Aug 20	2, 3, 5, 9
Spring sown		Mar. 10-Apr 1	July 5	July 20-Aug 15	Sept. 1	2, 3, 5, 9
Oregon						
Fall sown	399	Aug. 15-Feb. 1	July 5	July 15-Aug. 10	Aug 20	1, 2, 3, 8
Spring sown		Feb. 15-May 15	July 25	Aug. 5-Aug 25	Sept 15	Statewide, except Coast
California						
Fall sown	1,153	Oct 1-Apr 15	May 15	June 1-July 15	Aug 15	4, 5, 5A, 8
Spring sown		Mar. 1-May 1	Aug. 15	Sept. 1-Sept. 20	Sept. 30	Modoc, Siskiyou
Alaska	18	May 1-July 1	Aug. 15	Sept. 10-Sept 25	Oct. 5	Tanana & Matanuska Valleys

Table 1. Barley. Usual planting and harvesting dates, by State and principal producing areas

State and sowing season	1969 : harvested : acreage : (000)	Usual planting dates	Usual harvesting dates			Principal producing areas and counties
			Begin	Most active	End	
New York						
Fall sown	13	Sept. 1 - Sept. 15	July 15	July 25-Aug. 5	Aug. 10	4, 5
Spring sown		Apr. 20 - June 10	Aug. 5	Aug. 10-Aug. 20	Aug. 25	Statewide
New Jersey						
Fall sown	20	Sept. 10- Oct. 20	June 10	June 20-July 10	July 20	5, 8
Spring sown		Mar 20- Apr. 20	June 10	June 20-July 10	July 20	5, 8
Pennsylvania						
Fall sown	191	Sept. 10- Oct. 1	June 20	June 25-July 5	July 10	4, 5, 6, 7, 8, 9
Spring sown		Apr 25 - May 25	July 25	Aug. 1-Aug. 15	Aug. 20	1, 2, 3
Ohio	20	Sept. 5 - Oct. 15	June 20	July 1 -July 15	July 25	Statewide
Indiana	10	Sept. 5 - Sept. 25	June 10	June 15-June 25	July 1	4, 5, 6, 7, 8, 9
Illinois						
Fall sown	15	Aug. 20 - Sept. 20	June 20	June 25-July 15	July 15	4A, 6A, 7, 9
Spring sown		Apr. 5 - May 1	July 15	July 20-Aug. 1	Aug. 5	1, 3, 4
Michigan						
Fall sown	23	Sept. 5 - Sept. 15	July 1	July 5-July 20	July 30	8, 9
Spring sown		Apr 15 - May 30	July 15	July 15-Aug 5	Aug. 10	6, 7
Wisconsin	35	Apr. 20 - May 1	July 20	July 25- Aug. 5	Aug. 10	8, 9
Minnesota	685	Apr 15 - May 30	July 25	Aug 1 - Aug.20	Sept 10	1, 4
Iowa	4	Apr 1 - Apr. 20	July 10	July 15-July 25	Aug. 1	Statewide
Missouri	22	Sept. 10- Oct. 1	June 1	June 5 -June 15	June 20	4, 5, 6, 7, 9
North Dakota	2,206	Apr 20 - June 1	Aug. 1	Aug. 10-Aug. 25	Sept 5	Statewide
South Dakota	344	Apr 5 - May 10	July 15	July 25-Aug 10	Aug. 15	Statewide
Nebraska						
Fall sown	45	Sept. 1 - Oct. 5	July 1	July 5 -July 20	July 30	1
Spring sown		Mar 25 - May 1	July 1	July 5 -July 20	July 30	1
Kansas						
Fall sown	165	Sept 10 - Oct. 25	June 10	June 15- July 1	July 5	Statewide
Spring sown		Mar. 5 - Apr. 30	June 20	June 25- July 1	July 10	Statewide
Delaware	20	Sept. 20 - Nov 10	June 10	June 20- July 5	July 10	Statewide
Maryland	99	Sept. 15 - Nov. 10	June 10	June 20- July 10	July 15	Statewide
Virginia	117	Sept. 5 - Nov. 1	June 1	June 20 -July 1	July 15	2, 4, 5, 6
West Virginia	9	Sept. 10- Oct. 15	June 25	July 5 - July 20	Aug 1	6
North Carolina	55	Sept. 15 - Nov. 10	May 20	June 5- June 25	July 10	5, 8, 9
South Carolina	19	Oct. 1 - Dec. 1	May 15	May 20 - June 10	June 15	Statewide
Georgia	5	Sept. 10 - Dec. 1	May 15	June 1 - June 15	June 25	3, 5, 6, 7
Kentucky	41	Aug. 20 - Oct. 1	June 1	June 10-June 25	July 5	2, 3
Tennessee	17	Sept. 1 - Nov. 1	June 1	June 10-June 25	July 10	3, 4, 5

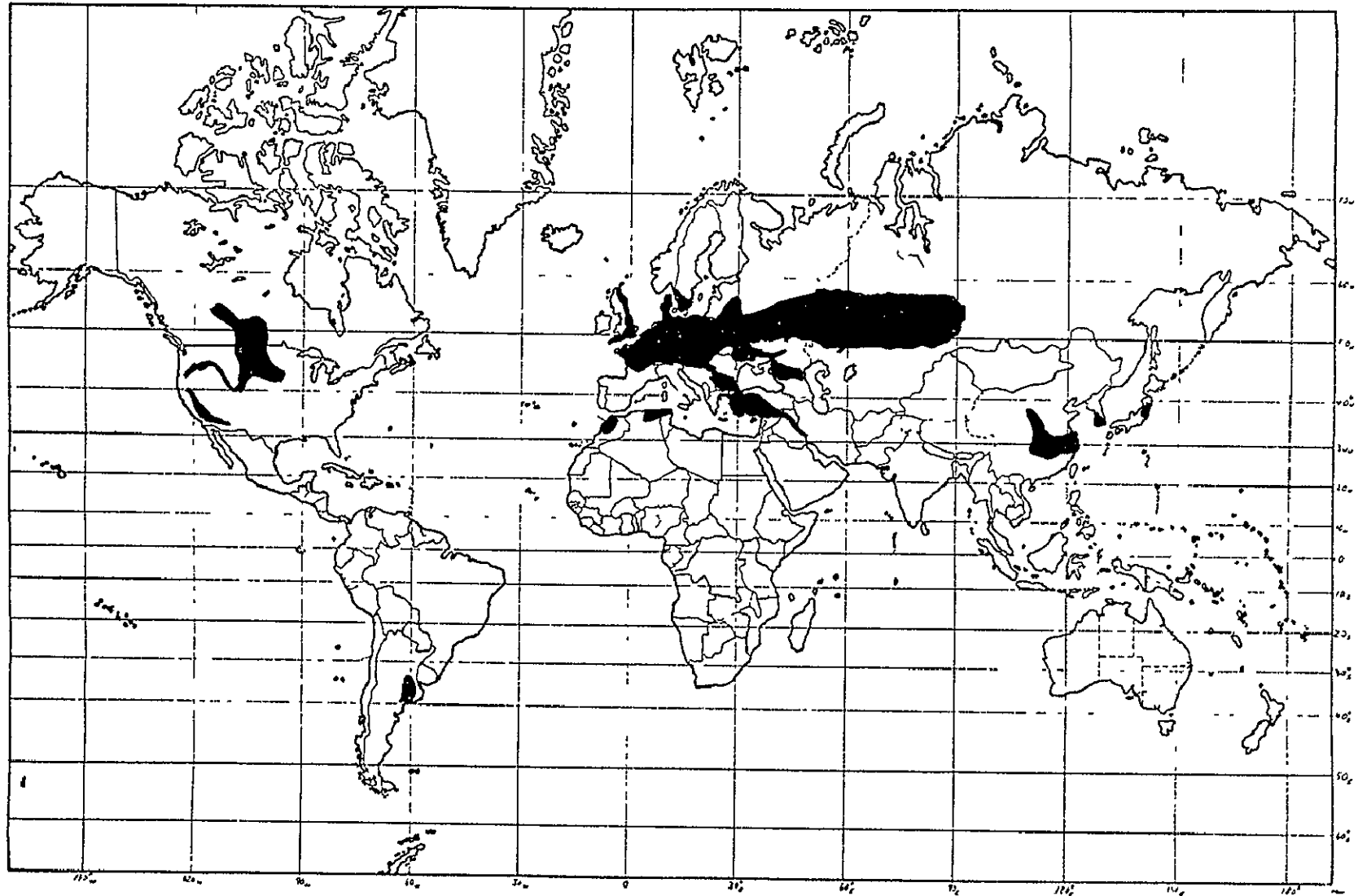
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# WHEAT



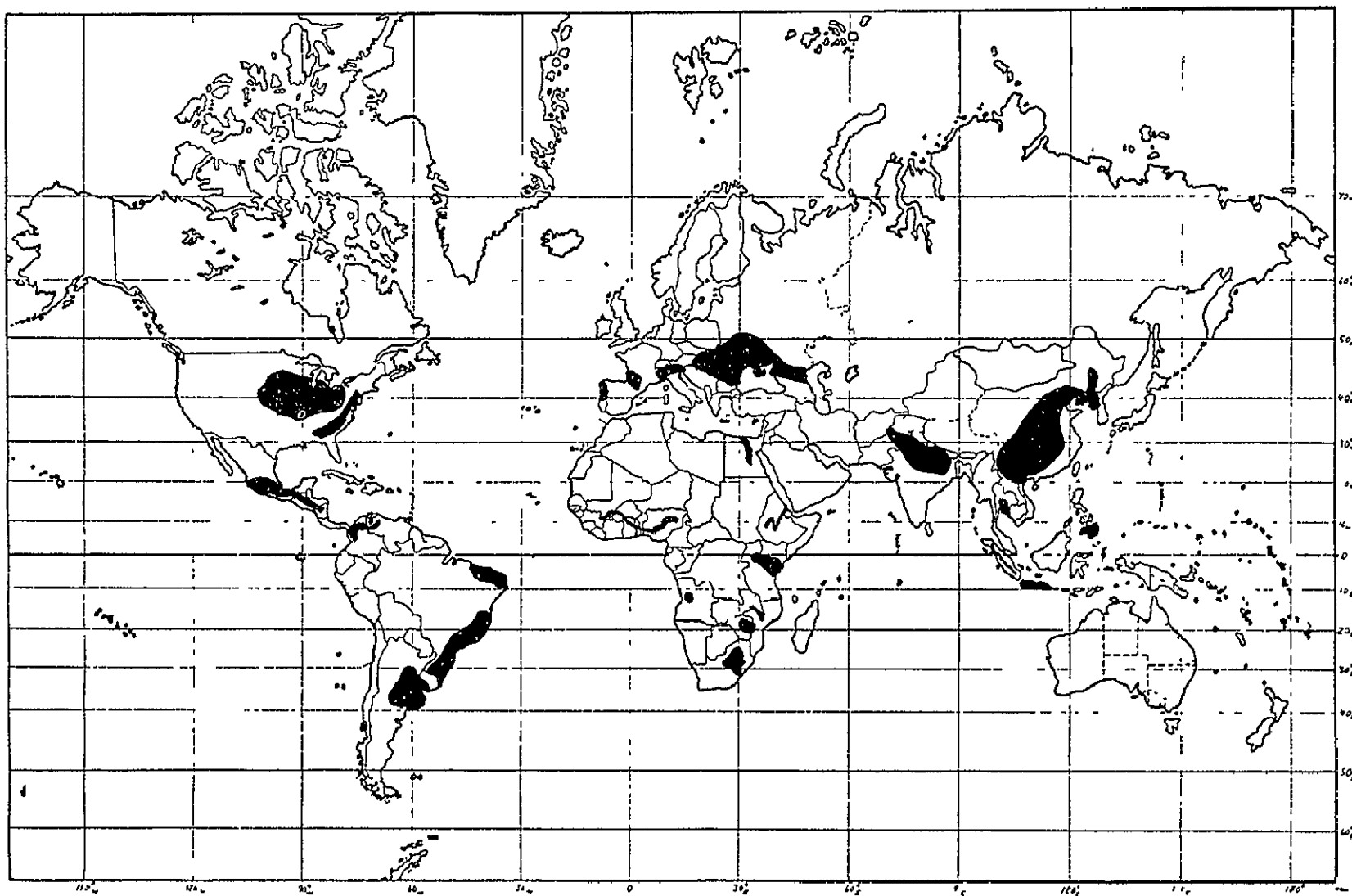


# BARLEY

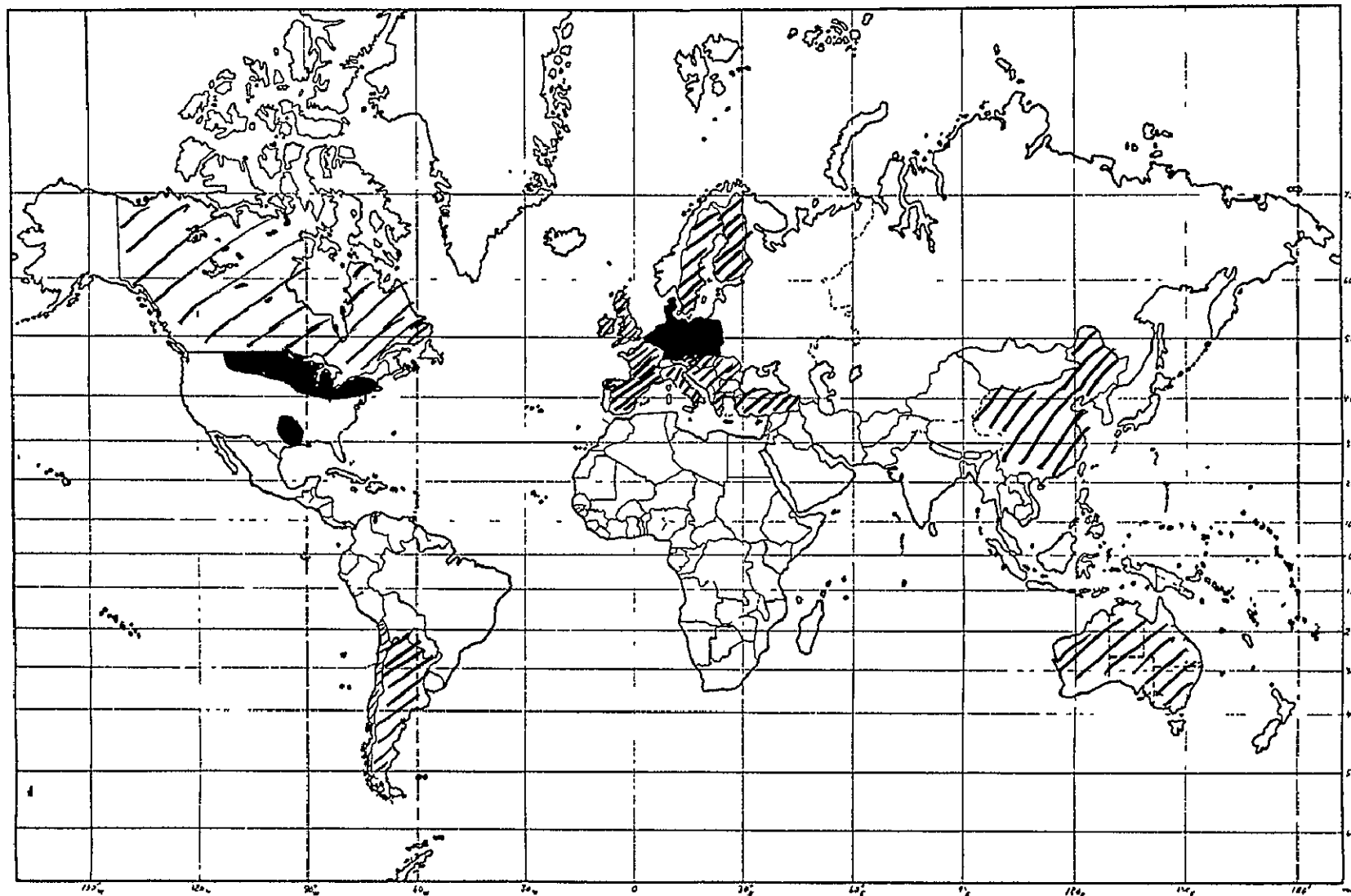


L-34

# CORN (MAIZE)

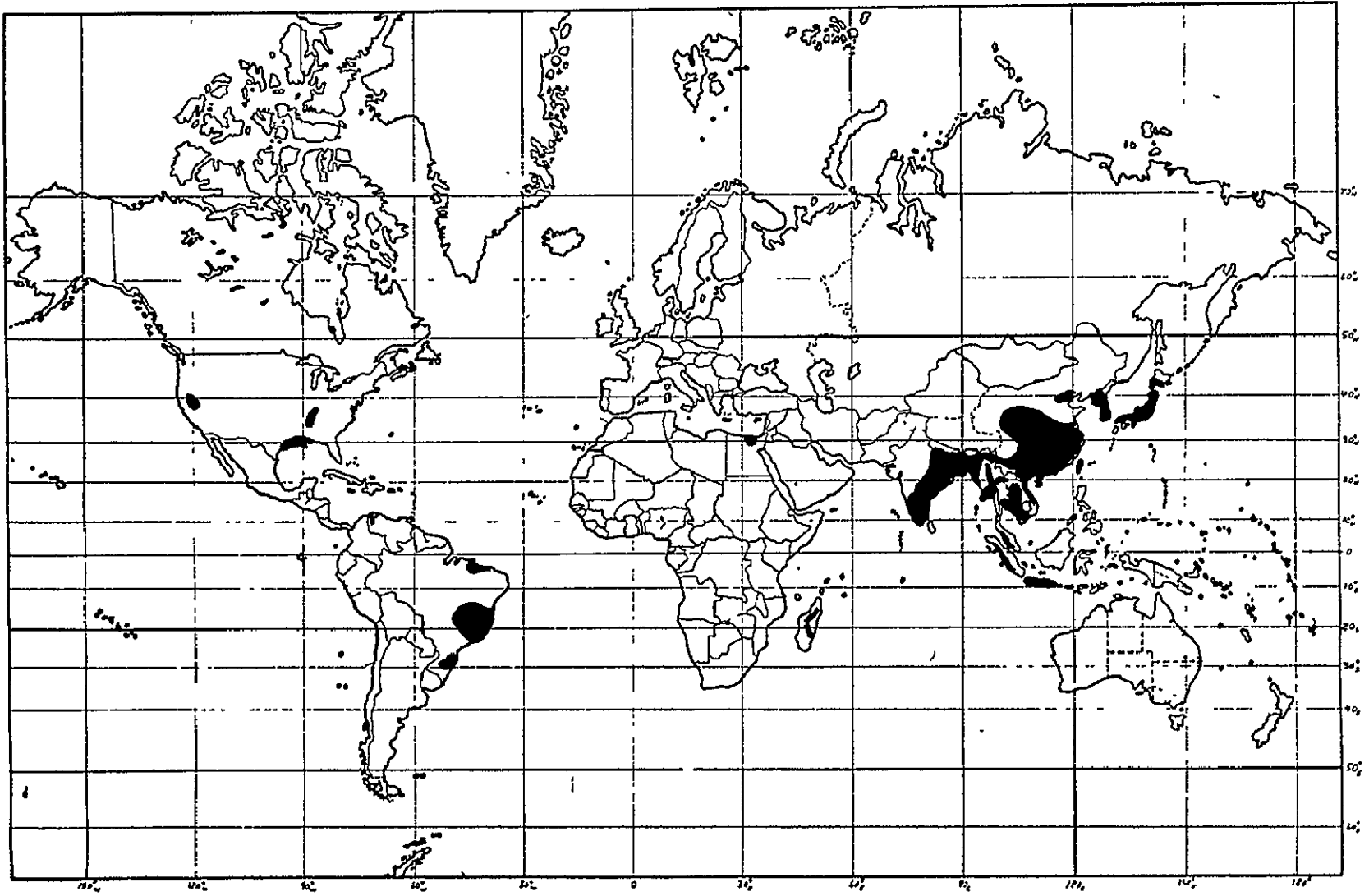


# OATS



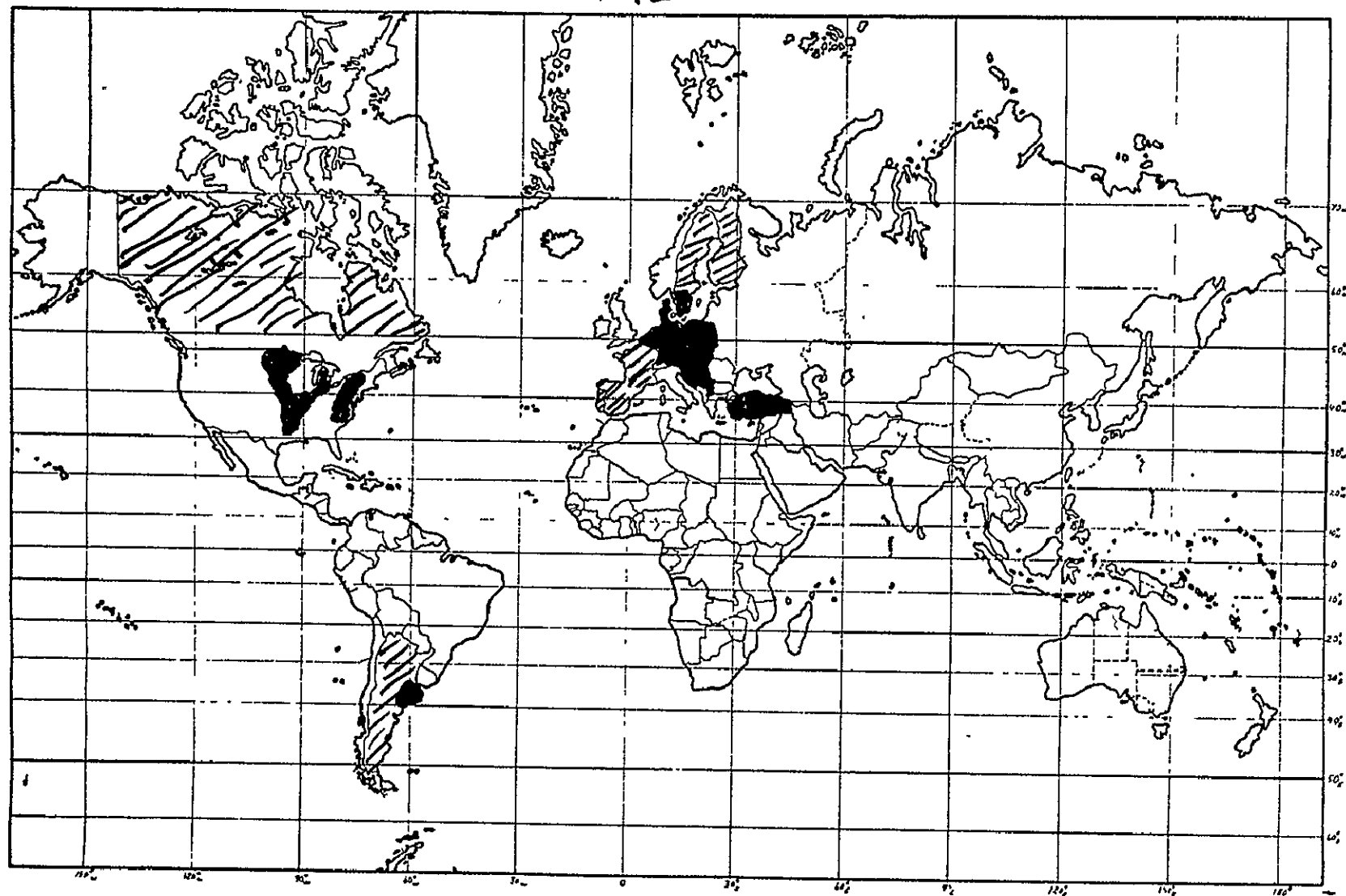
EXACT LOCATION  
WITHIN COUNTRY  
NOT KNOWN

RICE



# RYE

L-38



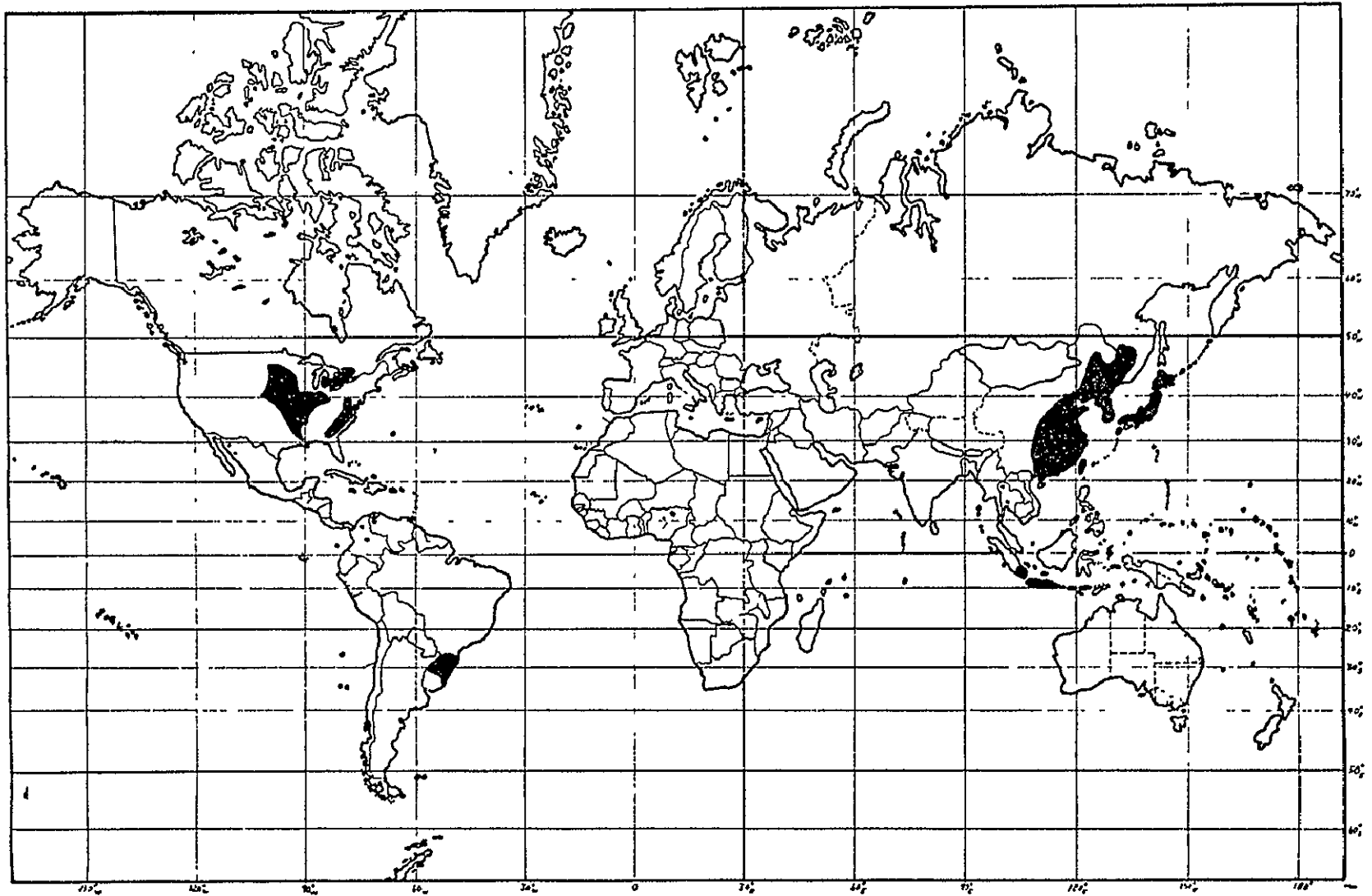
EXACT LOCATION  
WITHIN COUNTRY  
NOT KNOWN

# SOYBEANS

MAY  
OCT

I-39

AUG  
DEC



**APPENDIX M**  
**TOSS STATISTICAL SAMPLING**

## APPENDIX M

### TOSS STATISTICAL SAMPLING

This appendix contains a detailed discussion of the effort conducted as part of TOSS into the derivation of a US and a Global sampling plan for crop inventory by remote sensing. It contains a relatively concise review of the mathematics and statistics required in the formulation of a sampling plan and discusses the methodology developed in TOSS to formulate a multiple crop sampling plan.

#### M.1 STATEMENT OF PROBLEM

It is desired to use satellite remote sensing to monitor various crops in the ground both in the United States and in foreign countries whose production, importing or exporting impact the United States economically. The crops to be observed are barley, corn, oats, rice, rye, soybeans, and wheat. Although experimental effort is underway, there are as yet no operational ways to determine yield (i.e. bushels/acre) by satellite. For this TOSS study yields will be determined exogenously. Satellite sensing will be used to determine acreage only. Given fixed measurement accuracies, when and where should crop acreage be measured for maximum cost effectiveness?

The solution to be presented in this appendix will consider all seven crops in the United States and wheat only world-wide. The multiple crop solution for the United States can be applied mutatis mutandi to the global case. The theory of statistics will be employed to solve the problem.

The solution statement is divided into four sections:

- o An elementary introduction to statistics
- o A description of the solution methodology
- o Specific investigation results
- o Two appendices containing an illustration of strata construction and a list of sources



The purpose of this statistical sampling analysis is to supply answers adequate to permit satellite systems design, not necessarily to be implemented directly in an operational remote sensing system.

## M.2 STATISTICAL INTRODUCTION

### M.2.1 THE STATISTICAL SAMPLING APPROACH

A collection of objects for which it is desired to obtain information is known as a population. Examples are people in the United States, or farmland in the USSR. Each individual object is known as an element of the population—for example, a person in the United States. Farmland, however, is a collection of land expanses and as such does not exist as a set of discrete objects. A farm or a field consists of many square feet of farmland. Each square foot of farmland can be broken into smaller units of farmland, ad infinitum. Farmland is a continuous, not a discrete, population. Its formal treatment requires the so-called theory of measure from advanced mathematics. If however, we grant that there is a smallest unit of land area that our satellite sensor can "see", then farmland can be thought of as the discrete, finite collection of sensor images taken of the real-world farmland. The smallest seeable sensor image will be called a pixel. The pixels for a given piece of farmland are not uniquely determined, since the pixel borders can vary. (Measurement process is ignored here.) Replacing the continuous farmland by the discrete pixels is an approximation. In some ways it is similar to the infinitesimals of differential calculus used by engineers since the time of Newton. These pixels will be adequate for our purposes and will enable us to deal with the conceptually simpler discrete populations.

The population of pixels is large but finite. To determine information about our pixel farmland population, we could check every pixel. This is called an enumeration, or, census of the population. A census will certainly answer

any answerable question about a discrete finite population. But it may be costly. A second approach is to sample a subcollection of the population in any convenient fashion and to assume the whole population behaves like the sample. This approach can be economical and is often useful. If there are 200 million people in the United States and we want to know how many wear hats at least once a year, we could ask the first 200 people we see, multiply the number who say they do by one million and use that as our answer. But the first 200 people we see may have all been workers at a factory where safety hats are required. We have no way of knowing how good our answer is.

There is a third way to determine a population parameter (i.e., trait of elements of the population). It considers the economic costs of gathering information and the reliability of the information gathered. This method is called statistical sampling or probability sampling. By abstract "statistical" considerations population parameters are determined together with measures of confidence in the answer. The most economical methods for collecting the needed information are mathematically determined in accordance with estimated costs of the various phases of data collection. Examples of cost types are travel, data measurement, information processing.

Probability sampling requires some precise knowledge of the population and meticulous adherence to certain rules for choosing samples. There must be unambiguous definitions of the distinct samples that can occur. The probability of selection of each sample is determined. The process of selecting a sample is designed so that each sample will be chosen with probability equal to its determined probability of selection. The method for computing the estimate from the sample must be pre-determined and unique for each sample.

## M.2.2 POPULATION PARAMETERS AND CONFIDENCE

There are four types of population parameters, or characteristics that are commonly measured:

- o averages
- o totals
- o ratios of two totals or means
- o proportions of elements which fall into a particular class (have a particular attribute)

Examples:

- o average height of U.S. adults
- o total area of wheatland
- o ratio of smokers to non-smokers in U.K.
- o proportion of U.S. farmland planted in soybeans

The following notation is common and will be used here:

- o capital letters - population characteristics
- o lower case letters - sample characteristics
- o  $\bar{\cdot}$  (bar above letter) - average or mean ( $\bar{y} = (\sum_{i=1}^N y_i) / N$ )
- o letter without bar - total ( $y = \sum_{i=1}^N y_i$ )
- o P, p - proportions
- o  $\hat{\cdot}$  (circumflex above letter) - estimate of population parameter
- o N - number of elements in a population
- o n - number of elements in a sample
- o  $\mu$  - a population mean
- o  $\sigma^2 = \sum_{i=1}^N (y_i - \bar{y})^2 / N$
- o  $s^2 = \frac{1}{n} (\sum_{i=1}^n (y_i - \bar{y})^2) / (N-1)$
- o  $f = \frac{n}{N}$
- o  $V(\bar{y}) = \frac{s^2}{N} (1 - f)$  (for simple random sampling)

Note that characteristics must be represented by numbers for much of this to make sense. For averages, totals and ratios, we are clearly dealing in numbers, so this is no problem. For attribute sampling (proportion in a given class), an element is assigned the value 1 if it has the attribute (is in the class) and 0 otherwise. This works out nicely: the total is the number of elements in the class and the average is the proportion, P in the class.

$\sigma^2$  is called the variance of  $y_i$  for a finite population.  $V(\bar{y})$  is the variance of the mean  $\bar{y}$  from a simple random sample. A random sample is one in which all elements are equally likely to be chosen. The formula for  $V(\bar{y})$  for simple

random sampling is not a definition, but a provable fact.  $f$  is called the sampling fraction and  $1-f$  is called the finite population correction (fpc).  $\sqrt{\sigma^2}$  is denoted  $\sigma$  and is called the standard deviation.  $\sqrt{V(\bar{y})}$  is the standard deviation of the mean  $\bar{y}$ . It is frequently called the standard error and denoted  $\sigma_{\bar{y}}$ .

It should be noted that these definitions assume all elements of the population are equally likely to occur. This assumption is often not warranted. The more general definitions are in terms of so-called "expected values" or "expectations"; here, each term is weighted by its probability of occurrence. An understanding of expected value is not required for what follows.

Under a wide range of circumstances, when one wishes to estimate  $\bar{Y}$ ,  $\bar{y}$  represents a good estimate of  $\bar{Y}$  and  $\sigma_{\bar{y}}$  is a measure of how good the estimate  $\bar{y}$  is. The ratio  $\frac{\sigma_{\bar{y}}}{\bar{y}}$  is called the coefficient of variation, or, CV. It is a normalized standard error and represents precise information about the confidence with which  $\bar{Y}$  is estimated by  $\bar{y}$ .

### M.2.3 RANDOM SAMPLING, THE NORMAL DISTRIBUTION AND CONFIDENCE

If all elements of a population are equally likely to be chosen in a sample, then the sample is said to be a random sample and the sampling process is called random sampling. Suppose a population is randomly sampled many times and each time an estimate  $\bar{y}$  of the unknown population mean  $\bar{Y}$  is made. If a histogram of  $\bar{y}$  versus relative frequency of occurrence of  $\bar{y}$  is made, the histogram will tend to take a certain shape. It can be proven that as the number of samples is increased, the shape will become closer to the shape of the curve given by:  $p(\bar{y}) = \frac{1}{\sqrt{2\pi} \sigma_{\bar{y}}} e^{-\frac{(\bar{y} - \bar{Y})^2}{2 \sigma_{\bar{y}}^2}}$

This is a two-parameter curve that depends only on the variables  $\bar{Y}$  and  $\bar{y}$ ; it is called the normal (density) curve.

$$P(\bar{y}_0) = \int_{-\infty}^{\bar{y}_0} \phi(\bar{y}) d\bar{y} = \frac{1}{\sqrt{2\pi} \sigma_{\bar{y}}} \int_{-\infty}^{\bar{y}_0} e^{-\frac{(\bar{y} - \bar{Y})^2}{2 \sigma_{\bar{y}}^2}} d\bar{y}$$

is called the normal (cumulative) distribution.

When  $\sigma_{\bar{y}} = 1$  and  $\bar{Y} = 0$ , we have  $\phi(\bar{y}) = \frac{1}{\sqrt{2\pi}} e^{-\frac{\bar{y}^2}{2}}$

which is called the standard normal curve.

For finite populations,  $p(\bar{y})$  is the probability that  $\bar{y}$  will occur.  $P(\bar{y}_0)$  is the probability that  $\bar{y} \leq \bar{y}_0$ .

Let  $P(|\bar{y} - \bar{Y}| \leq t \sigma_{\bar{y}})$  denote the probability that  $|\bar{y} - \bar{Y}| \leq t \sigma_{\bar{y}}$  for fixed  $t$  and  $\sigma_{\bar{y}}$ . That is,  $-t \sigma_{\bar{y}} \leq \bar{y} - \bar{Y} \leq t \sigma_{\bar{y}}$ .  $t$  is called the (standard) normal deviate.  $[\bar{Y} - t \sigma_{\bar{y}}, \bar{Y} + t \sigma_{\bar{y}}]$  is called the confidence interval (about  $\bar{Y}$ ) corresponding to the normal deviate  $t$ .  $P\{|\bar{y} - \bar{Y}| \leq t \sigma_{\bar{y}}\}$  is called the confidence level. It is the probability that a given sample mean  $\bar{y}$  will be within  $t \sigma_{\bar{y}}$  of the population mean  $\bar{Y}$ .

Working in polar coordinates, it's easy to show that  $\int_{-\infty}^{\infty} \phi(\bar{y}) d\bar{y} = 1$ .

By elementary calculus,  $P(|\bar{y} - \bar{Y}| \leq t \sigma_{\bar{y}}) =$   
 $P(-t \sigma_{\bar{y}} \leq \bar{y} - \bar{Y} \leq t \sigma_{\bar{y}}) =$   
 $P(\bar{Y} - t \sigma_{\bar{y}} \leq \bar{y} \leq \bar{Y} + t \sigma_{\bar{y}}) =$   
 $\frac{1}{\sqrt{2\pi} \sigma_{\bar{y}}} \int_{\bar{Y} - t \sigma_{\bar{y}}}^{\bar{Y} + t \sigma_{\bar{y}}} e^{-\frac{(\bar{y} - \bar{Y})^2}{2 \sigma_{\bar{y}}^2}} d\bar{y} =$   
 $\frac{1}{\sqrt{2\pi}} \int_{-t}^t e^{-\frac{x^2}{2}} dx$

The last equality follows from the change of variable  $x = \frac{\bar{y} - \bar{Y}}{\sigma_{\bar{y}}}$

So the confidence level ( $C_t$ ) depends only on  $t$  and the standard normal distribution. Values of  $t$  versus  $C_t$  have been tabulated. Some commonly used values are:

$t$	1.0	1.96	2.58
$C_t$	.68	.95	.99

In practical terms, this means that one can determine bounds on  $\bar{Y}$  and be, say 95% sure (confident) that the bounds are correct. For  $C_t = 95\% = .95$ ,  $t = 1.96$ .

Hence, we know that if we take a large number of samples and compute their average,  $\bar{y}$ , then 95% of the time  $\bar{y} - 1.96 \sigma_{\bar{y}} \leq \bar{Y} \leq \bar{y} + 1.96 \sigma_{\bar{y}}$ .

But  $\sigma_{\bar{y}} = \frac{S^2}{n}$  (1-f) where we can approximate  $S^2 \simeq \left( \sum_i (\gamma_i - \bar{y})^2 \right) / (n-1)$ .

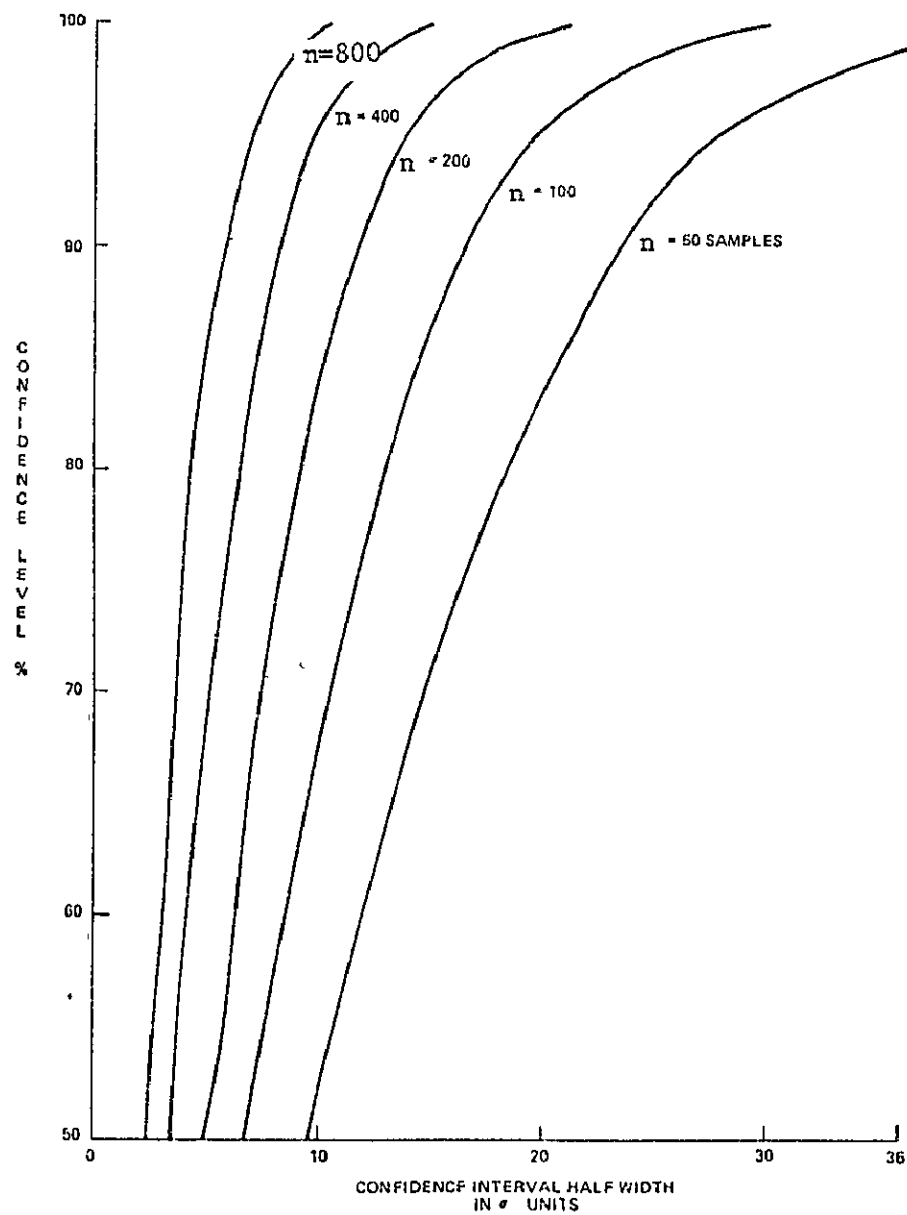
Hence we can determine (say) the 95% confidence interval for a given number of samples,  $n$ , provided  $n$  is large. In practice,  $n \geq 60$  is usually sufficient for the above procedure to yield reasonable accuracy.

The opposite problem can also be solved. Suppose we want to be 95% confident that  $\bar{Y} \in [\bar{y} - K, \bar{y} + K]$  for some constant  $K$ . Then  $K = 1.96 \sigma_{\bar{y}} = 1.96 \frac{S^2}{n} (1 - f)$ . If we have an estimate for (or know)  $S^2$ , then the number of samples needed is  $n \simeq 1.96 \frac{S^2}{K} \frac{1}{1-f}$  assuming  $f=n/N$  is small.

The following page shows the relationship between number of samples  $n$ , confidence interval half-width in  $\sigma$ -units,  $t$ , and confidence level,  $C_t$ . It is assumed that the sampling fraction is small and that the normal distribution applies.

# RANDOM SAMPLING

## FLUCTUATION ERROR FOR LARGE SAMPLES



#### M.2.4 VALIDITY OF THE NORMAL CURVE FOR COMPUTING CONFIDENCE

A great deal of theoretical work has been done to investigate when the normal curve can be used for computing confidence. Here are the basic results.

For infinite populations with finite standard deviation, the distribution of sample means tends to normality. For sampling without replacement from finite populations under certain technical assumptions (cf. (5) P. 38) the normal curve yields approximately correct confidences when  $n$  is sufficiently large.

Two practical questions must be answered in order to know when the normal approximation can be used for computing confidence. When is a population approximately normally distributed? For a given population, how many sample points are required for the normal approximation to be reasonably accurate?

Extreme population elements tend to cause non-normality. Removing them tends to reduce skewness - or, asymmetry - and yield a more normal population. The extreme elements are known as outliers. Outliers can be sampled or censused independently. A distribution is called positively skewed when its outliers tend to be large rather than small. For positively skewed distributions, to use the normal approximation, it is reasonable to require that  $n > 25 G_1^2$ , where  $G_1 = \frac{1}{N^2} \sum_{i=1}^N (y_i - \bar{Y})^3$ . This rule usually results in a 95% confidence statement being correct at least 94% of the time. Cochran, section 2.13 has a fuller discussion of this matter.

Q. M. West\* in 1951 published a study of acres devoted to crops on 556 farms in New York. For his data,  $G_1 = 1.9$  so  $n \geq 90$ . For  $n = 100$ , West found the distribution of acres in crops to correspond closely to the theoretical normal. In general, normality assumptions should be validated by checking against data collected in the sampling process.

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\*West, Q.M. (1951). The results of applying a simple random sampling process to farm management data. Ag. Exp. Station, Cornell University



### M.2.5 THE BINOMIAL AND SAMPLING FOR PROPORTIONS

If an experiment is performed in which the outcome of each trial is independent of all previous outcomes, then the successive trials are said to be independent. If each trial has only two possible outcomes, then the set of independent trials is called Bernoulli trials. It is standard practice to describe one of the outcomes as "success", or the number 1. The other outcome is "failure", or the number 0. This corresponds with attribute sampling as mentioned previously. Note, however, that regarding successive samples without replacement as Bernoulli trials is an approximation. For, the first sample is a random sample from a population of size  $N$ ; the second from  $N-1$  elements, etc. If  $n \ll N$  (" $\ll$ " means "much less than"), this is a good approximation. This approximation will be assumed accurate in what follows.

Let  $y_i = 1$  or  $0$  according to whether the trial outcome was "success" or not. Then  $\bar{Y} = \frac{1}{N} \sum_{i=1}^N y_i$ . But  $\frac{\sum y_i}{N}$  is the proportion  $P$  of the population in the class "success". So  $\bar{Y} = P$ . Let  $Q = 1-P$ . Then  $\sigma^2 = \frac{1}{N} \sum_{i=1}^N (y_i - P)^2 = P(1-P)^2 + Q(0-P)^2 = PQ^2 + QP^2 = PQ(Q+P) = PQ$ .

One can think of successive sample points found by sampling as Bernoulli trials. Then 1 denotes the outcome that a sample point has a certain attribute - e.g., it is wheatland in the farmland population. Then  $P$  is the fraction of wheatland and also the probability that a given sample point will be wheatland.

Since  $S^2 = \frac{N}{N-1} \sigma^2$ ,  $S^2 = \frac{N}{N-1} PQ$  and  $V(p) = \frac{S^2}{n} (1 - f) = \frac{S^2}{n} \frac{N-n}{N}$

$$\frac{PQ}{n} \frac{N-n}{N-1},$$

$\frac{N-n}{N-1}$  is the fpc; if  $n \ll N$ , then

$$V(p) \doteq \frac{PQ}{n}, \sigma_p = \sqrt{V(p)} = \sqrt{\frac{PQ}{n}} \quad \text{and}$$

$$CV(p) \doteq \frac{\sqrt{\frac{PQ}{n}}}{P} = \sqrt{\frac{Q/P}{n}}$$

The symbol " $\doteq$ " means "is approximated by".

It is an easily derivable fact that for any constant  $c$ ,  $V(cy) = c^2V(y)$ . Hence,  $CV(Np) = \frac{\sigma_N}{NP} = \frac{N \sigma_p}{NP} = \frac{\sigma_p}{P} = CV(p)$ . We now have enough information to determine the number of sample points theoretically needed to find the proportion of, say, wheatland in farmland with an arbitrary confidence or CV requirement. After sampling, we can compute CV and  $\sigma_p$  (standard error) from the sample to see if our theoretical approximations were reasonable.

Here is an outline of the procedure. From a relatively inexpensive previous sample, we have an estimate  $P_0$  of  $P$  in a given population. We want a sample size  $n$  sufficiently large so that  $CV = C_0$ , a constant determined by exogenous constraints. Since  $CV(p) = \frac{\sqrt{Q/P}}{\sqrt{n}}$ ,  $n = \frac{Q/P}{(CV)^2} = \frac{1-P_0}{P_0 C_0^2}$ . Unless in  $n \ll N$ , this approximation is invalid and we must use the more accurate formula

$$V(\hat{p}) = \frac{pq}{n} \frac{N-n}{N-1}$$

But  $CV(\hat{p}) = \sigma_{\hat{p}}/P = \sqrt{V(\hat{p})}/P$ , so  $(CV)^2 = V(\hat{p})/P^2 = \frac{Q/P}{n} \frac{N-n}{N-1}$

$$\text{and } n = N / \left( 1 + P_0 C_0^2 \frac{N-1}{1-P_0} \right).$$

Since  $\sigma_p = P \times CV$ , the confidence level corresponding to any confidence interval (of half-width  $t\sigma_p$ ) can be looked up in a normal table.

After the sample is taken, the  $p$  and  $\sigma_p$  from sampling can be compared with  $P_0$  and  $P_0 \times C_0$ , respectively.

#### M.2.6 THE SIGNIFICANCE OF POPULATION

The choice of population, or sampling frame, is crucial to the entire sampling procedure. Consider the case of determining the amount of wheatland in the U.S. If the population is considered to be the entire United States, then  $P$  might be, say, 1%. If only farmland is considered,  $P$  might be 20%; if only grainland is considered,  $P$  might be 40%. Define  $P_{US} = .01$ ,  $P_F = .2$ ,  $P_G = .4$ .

Assume a requirement  $CV = .1$  - i.e.  $\frac{\sigma_{NP}}{NP} = \frac{1}{n} \sqrt{\frac{Q/P}{n}} = .1$ . Then  $n = 100 \frac{Q}{P} \Rightarrow$   
 $n_{U.S.} = 9900$ ,  $n_F = 400$ ,  $n_G = 150$ . Assuming sampling cost  $c$  is proportional  
to number of samples,  $c_F = 2.7 c_G$  and  $c_{U.S.} = 24.8 c_F$ . Clearly, any reduction  
of extraneous population can result in large cost savings.

#### M.2.7 THE RANDOM VARIABLE AND CHOICE OF VARIATE

A random variable (RV) or variate is a function from elements of the (discrete)  
sample space to the real numbers. The number  $y_i$  attached to the  $i^{th}$  population  
element until now is simply a value taken on by the RV  $Y$ . Expressed in these  
terms, we can, for example, define Bernoulli trials by  $P(Y = 1) = p$  and  $P(Y = 0)$   
 $= 1 - p$ . There may be several different numbers attached to each element of  
the population. They can be represented by functions denoted  $X, Y, Z$ , etc.  
The choice of random variable is a theoretical modeling problem: one chooses  
an RV so that the mean, standard error, etc. will be relevant and informative  
numbers. For example, suppose one is interested in U.S. wheat production and  
one can remotely sense land elements (called pixels). Consider pixels as pop-  
ulation elements. One can assign many different and reasonable RV's to this  
population such as: Yield in bushels per planted wheat acre,  $Y$ ; the binomial  
 $D = \begin{cases} 0, & \text{if } < 50\%, \text{ wheat present} \\ 1, & \text{if } \geq 50\% \text{ wheat present} \end{cases}$ ; production,  $P$ , in bushels.  $\frac{1}{N} \sum D$  summed  
over pixels is a rough measure of planting density-that is, the proportion of  
the population planted in wheat. Functions of these variates are also RV's  
by definition. Thus  $I = Y \times D$  is a valid RV, which we will call production  
intensity.  $I$  has units of  $\text{bu}/(\text{wheat acre}) \times (\text{wheat acres})/\text{population}$   
 $\text{acres}) = \text{bushels per acre of population}$ . For investigating wheat population,  
all of these variates are of value. The choice of which ones to use depends  
on specifics of sampling techniques and purposes.

#### M.2.8 STRATIFICATION

A population can be broken into subpopulations either for purposes of statistical analysis or to determine information about the subpopulations. The state of Washington may be divided into five subpopulations according to wheat planting density. It may then be possible to allocate a fixed number of sample points among these subpopulations in a manner that will give more accurate sampling information about Washington than a random allocation throughout Washington. The information about each of the subpopulations may be of no practical value. But if sampling efficiency was thereby increased, the mathematical partitioning of the population will have value in that it reduced the cost of sampling. This occurs if the variances in each of the subpopulations are small enough to permit increased accuracy in the overall variance. This happens when the variance between the subpopulations is significant.

Similarly, when sampling for wheatland in the U.S., it may be desirable to obtain estimates for individual states. It is likely that these individual states are not microcosms of the entire U.S. with respect to wheatland distribution. Hence each state will have its own accuracy and sample size requirements. The results for each of the states can then be mathematically aggregated to determine an overall U.S. accuracy, which depends on the total number of samples and the sampling plan in each state.

In both of the above two cases, the population is said to have been stratified. The subpopulations are called strata. The process of choosing the strata is called stratification. The resulting sampling plan is called a stratified sampling plan.

A subpopulation need not be a stratum. For example, a sampling unit consisting of more than one population element is a subpopulation but not a stratum.

### M.3 METHODOLOGY

#### M.3.1 OVERVIEW

For each crop, planting density (the variate D) will be used to arrive at acreage estimates using the theory of sampling for proportions. The U.S. will be divided into states. Within each state, planting density will be used to determine strata. The number of samples to be placed in each stratum will be such as to optimize sampling efficiency - i.e., get the most accuracy with the smallest number of samples. This optimal allocation of samples is called Neyman allocation. The term implies stratification.

For any requested U.S. CV,  $\text{Var}(p)$  will be determined at the U.S. level and converted to state level sample size requirements using Neyman allocation. Neyman allocation will then be used within each state on the planting density strata.

For the multiple crop case, the proportional number of samples needed for each crop in each county will be determined. The maxima of these numbers for each county will be added to get the number of samples to be used for each stratum, for each crop in the state. The resulting accuracies for each crop at the state and national levels will then be computed. The number of samples will be increased by a factor for each state. That factor will be determined from cloud cover data. It is needed because clouds prevent the sensing of samples.

Actually two cases will be considered for the U.S.: multiple crops and wheat only. The latter differs only in that only one crop is processed and so no maxima are chosen at the county level.

In the world case, significant countries are chosen and processed for the wheat only case. The countries are treated mathematically as strata in the

population of farmland of significant foreign wheat producing countries. They play the same role as states in the United States. However, only the U.S.S.R. is further stratified.

In practice, it proved to be unnecessary to stratify within states for the "wheat only" domestic plan. Because an estimate was good enough for systems design purposes, the detailed multiple crop calculations were not carried out.

### M.3.2 THE CHOICE OF VARIATE FOR STRATIFICATION

There are three prime candidates for random variable: planting density, harvesting density and production intensity. Planting density is acres planted per acre of population. Harvesting density is acres harvested per acre of population. Production intensity is bushels harvested per acre of population. Theoretically, they are equally valid alternatives. The choice must be based on the actual problem at hand. A satellite sensor incapable of determining yields is to be used to measure acreages devoted to crops. The yields will be determined exogenously so that production estimates can be made. Harvesting density depends partly on cropping practices. In certain portions of Kansas, for example, winter wheat is commonly planted as a cover and forage crop with no intention of harvesting it unless wheat prices become extraordinarily high. Usually, however, crops are planted for harvesting and are not harvested only if bad weather, floods, or pestilence ruins the crop. Assuming crop failures to be a random event, then, recent planting density information is a better measure of expected harvesting density than recent harvesting density. Furthermore, non-harvesting practices can be accounted for independent of the sampling plan by finding out the historical relationship between planted and harvested acreage by location (using regression analysis). Moreover, the acreage sensed by the satellite usually depends on what was planted; it certainly does not depend on merely what was harvested. For our purposes, planting density is a more useful random variable than harvesting density.

Let  $I$  be production intensity; let  $D$  be planting density; and let  $Y$  be yield (bushels per planted acre). Then  $I = Y \times D$ . From this it is clear that production intensity includes planting density as well as yield and weights these two factors equally. Although the satellite sensor cannot determine yield, it is the purpose of the system (including ground processing) to determine production. It has been determined for the U.S. that production estimation errors are caused in approximately equal measure by errors in yield and acreage measurement. The most efficient use of the satellite is for it to spend as much time as possible determining acreages where production is maximal. In other words, given two wheat fields of equal size, their relative importance for production estimation is equal to the ratio of their yields. Clearly, given two equally -sized land areas, the one with higher planting density has more planted acreage. Other things being equal, it is more important for production estimation. Again, the ratio of planting densities is a measure of this relative importance. Hence production intensity is a better random variable than either planting or harvesting density.

However, stratification using a variate other than the one to be measured presents some difficult technical problems.\* Planting density times population acreage equals planted acreage. So for these reasons, planting density will be used as the variate.

### M.3.3 THE CHOICE OF DATA

In designing a sampling plan, one must consider the cost of designing the plan in addition to required accuracy and operational costs. In the case of a plan

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\* cf. Cochran, section 5 A.6 for a discussion of these problems and the present state of mathematical knowledge in this area.

design for a theoretical study, the design cost is in fact the only immediate actual cost. The plan must be viable, but need not be more detailed than is required for the study. In particular, it is not necessary to conduct an independent primary survey of the population to accomplish the goals of this study. It is enough to work with USDA and FAO data currently available.

To determine which data to use, study requirements must be assessed. It is necessary to determine system load as a function of crop acreage estimation accuracy for a feasible and efficient sampling plan. Since planting-growth-harvest cycles are seasonal and location-dependent, the sampling plan must vary by location throughout the year. Furthermore, since population is constantly shifting, a continuing general survey is necessary so that sampling plans in future years will also be efficient. The plan must also take into account technological limitations.

The simplest procedure for sizing the operational system requirements is to look at the worst case, -i.e., the peak system-load month. Crop maps and -calendars-developed in the TOSS study show that peak load occurs in June both domestically and world-wide. Neither direct nor indirect planting density data is generally available on a monthly basis. Fortunately, however, during June all crops of interest are in the ground in all regions significant to the study. Hence, annual acreage data can be used as an approximation for acreage in the ground in June. This is, however, only an approximation. The same land may be used for more than one planting. Two or even three soybean plantings occur in some regions of the U.S.

A second problem is in the definition of the crops themselves. Wheat may be winter wheat, durum wheat or other spring wheat. Even though USDA has data for each of these, the varieties of wheat are highly interchangeable economically



and probably indistinguishable with near-term remote sensors. So wheat will be considered as a single crop. This results in data distortion due to multiple planting and high densities in some regions.

The resulting error in system load estimation is felt to be tolerable for this study. This is particularly true because another estimate - the physical amount of land to be sampled for each independent sample point - will be conservative. Here, "conservative" means requiring more system resources. It is conservative in the sense that a system that can handle the proposed theoretical work load has a high probability of successfully handling the actual operational load. This actual load can be accurately determined only by truly extensive and intensive analysis of the population.

The problem of classification is that of determining what a given pixel represents - whether it's wheat or corn, etc. The classification problem is of major system concern due to limited technological know-how in this area. In developing a sampling plan it is possible to avoid most of the problems connected with classification by regarding classification error as one aspect of measurement error. If this is done, then acreage estimation error can be regarded as a variance equal to the sum of component variances, which include measurement and sample fluctuation errors. The term "sample fluctuation error" is here synonymous with standard error of the estimated proportion ( $\sigma_p$ ). For a fuller discussion of acreage estimation error as a sum of variances, consult a memorandum by Wally Tyner entitled Analysis of Different Approaches to Crop Forecasting Error. It can be found as an attachment to a memo from R.J. Kalter to William Moffat on NASA Crop Forecasting and Economic Analysis Study dated 16 October 1974. The work was done at New York State College of Agriculture and Life Sciences at Cornell University in Ithaca, New York. The above approach is a simplification of the full problem since the variables may be

dependent. For example, classification error may depend on population proportion in the portion of the population being sampled. The proportion in turn depends on the sampling plan. Whether such dependence actually exists depends on the classification algorithm chosen.

Due to difficulties in classification and the temporal nature of the planting-growth-harvest cycle, it is desirable to fix in advance the aggregate of pixels to be periodically sampled. Due to extensive pre-processing requirements and intensive local information requirements (acquired through a process called training) it is uneconomical to sample isolated pixels. An aggregate of population elements sampled as an entity is called a sample unit (SU). After consideration of processing and equipment constraints, an SU has been chosen to be a square, four miles on a side. Hence, each year SU's will be allocated in advance. Because useful agricultural sensors cannot see through clouds, it will be necessary to choose in advance enough SU's so that an acceptable number of SU's will be seen with satisfactory frequency. This acceptable number can be determined using confidence notions as discussed in the statistical introduction.

Finally, it is necessary to define a population which, on the one hand is readily discernible and on the other hand is not so large that crops of interest are rarely in it. Three populations for the U.S. were considered in this study. The first is the entire land mass of all states which grow crops of interest. It was found that crops of interest are rare in this population. The practical result is that a census of this population is required because of the size of an SU. The second is the land mass of only the seven crops of interest. Locating this population with acceptable accuracy is at present too difficult a task. The third method, which is what was actually used, is to define the population as all the farmland (cultivated or fallow) in the states

of interest for the U.S. Globally, the population is just arable land. The information needed to design such a sampling plan is available. For the U.S., it consists of USDA county data, which is based on a national agricultural census completed every five years. 1974 census data is now available. Data on arable land in other countries comes from a variety of sources including several departments of the U.S. federal government and FAO of the United Nations. An actual survey based on these figures is possible. County area frame maps are kept by USDA. Foreign maps are probably less accurate but still acceptable. The crop maps and calendars generated by the TOSS study are detailed enough for careful systems design. They are not adequate for actually implementing the plan. This is as it should be. By the time an operational system is built, population shifts would have invalidated crop maps with greater detail than those generated in this study.

#### M.3.4 CLUSTERING

A sampling unit is an aggregate of elements sampled together. If more than one element is in an SU, the SU is called a cluster. That is, the sampling unit itself is chosen by statistical method - e.g., at random. But each sampling unit is a set of elements that were fixed in advance. Hence, the elements themselves are not chosen by a statistical process. Clustering is the tendency of elements to be dependent (i.e., not independent). The natural question is how many independent elements can be regarded as existing in one sampling unit. The number  $n$  of elements needed to achieve a certain confidence has to be translated into a number  $n'$  of SU's needed to achieve that same confidence. If the effective number of independent elements in an SU were a constant  $k$ , the answer would simply be  $n' = n/k$ . And it would remain to determine  $k$ . Formally, there are several ways to get at this problem. One method will be presented here.

Define the following:

- $Y$  - a random variable  
 $y_{ij}$  - the value of  $Y$  for the element  $j$  of SU  $i$   
 $y_i = \sum_j y_{ij}$  - the total for SU  $i$  of  $Y$   
 $N$  - the number of SU's in the population  
 $M$  - the constant number of elements in each SU  
 $\bar{y} = \sum y_i / N$  - the SU mean  
 $\bar{\bar{y}} = \sum y_i / NM = \bar{y} / M$  - the sample element mean

Then the variance of the population elements is

$$s^2 = \frac{\sum_{i,j} (y_{i,j} - \bar{\bar{y}})^2}{NM-1}$$

The intracluster correlation coefficient is defined by

$$\rho = \frac{2 \sum_i \sum_{j < k} (y_{ij} - \bar{\bar{y}})(y_{ik} - \bar{\bar{y}})}{(M-1)(NM-1) s^2}$$

Here  $j$  and  $k$  both vary through each SU subject to  $j < k$ . The numerator represents a sum of  $N \binom{M}{2} = \frac{NM(M-1)}{2}$  terms - one for each pair of elements in each SU.

If  $n$  clusters are randomly sampled from the population of  $N$  clusters with  $M$  elements each, then the sample mean per element  $\bar{\bar{y}} \stackrel{o}{=} \bar{\bar{y}}$  and

$$V(\bar{\bar{y}}) = \frac{1-f}{n} \frac{NM-1}{M^2(N-1)} s^2 (1 + (M-1)\rho).$$

taking  $\bar{\bar{y}}$  as  $p$  in sampling for proportions, we have  $\sigma_p = \sqrt{V(\bar{\bar{y}})}$  so that we could determine confidence as a function of sample size  $n$ . Here  $n$  is the number of SU's to be included in the sample; each SU contains  $M$  elements. This method is theoretically sound. Unfortunately, not enough data exists to get good

estimates of  $\sum_{j < k} (y_{ij} - \bar{Y})(y_{ik} - \bar{Y})$  for each SU for crops over large areas.

Estimates are available in certain areas of the U.S. where detailed experimental investigations have been carried out\*. The variability, however, is too large to generalize the results. The value of  $\rho$  depends heavily on crop, location and season. A fuller discussion of clustering is contained in Cochran, Chapter 9.

The analysis which follows is in terms of independent elements. Hence its conclusions are independent of the amount of clustering (i.e., the value of  $\rho$ ).

However, conversion of these results to system load requirements requires a means of converting from number of independent samples to number of SU's

required. The extremely conservative assumption that these numbers are equal will be made. As previously stated, an SU is a square, four miles on a side.

#### M.3.5 NEYMAN ALLOCATION IN SAMPLING FOR PROPORTIONS

The distributing of sample points across a population is called allocation.

Allocation across strata to minimize variance is called optimal, or Neyman allocation. For agricultural sampling it usually turns out to be only slightly superior to a computationally simpler method known as proportional allocation.

But since automatic data processing will be used in the operational system, the difference in computational cost is negligible. On the other hand the economic benefits involved are so large that even a small increase in sampling efficiency is worthwhile.

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- \* 1) Jessen, R.J. Statistical Investigation of a Sample Survey for Obtaining Farm Facts, (June 1942), Ag. Exp. Sta, Iowa State College of Ag.
- 2) Von Steen, "Crop Identification and Acreage Measurement Utilizing ERTS Imagery, April 1974.

Let  $n$  be the number of samples to be distributed among the  $L$  strata  $h = 1, 2, \dots, L$ . Let  $N_h$  denote the number of elements in stratum  $h$ ;  $n_h$ , the number of samples to be allocated to stratum  $h$ ;  $P_h$ , the proportion of stratum  $h$  in a given class; and  $Q_h = 1 - P_h$ . The number of elements in the entire population is  $N = \sum_{h=1}^L N_h$ .

The fraction of the population in each stratum is  $W_h = N_h/N$ . Assume  $N_h \gg L$  for  $h = 1, \dots, L$ . Then the Neyman allocation formula is

$$n_h = n \frac{N_h \sqrt{P_h Q_h}}{\sum_{i=1}^L N_i \sqrt{P_i Q_i}} = n \frac{W_h \sqrt{P_h Q_h}}{\sum_{i=1}^L W_i \sqrt{P_i Q_i}}$$

If it is desired to determine  $n$  for a given confidence, use the following procedure. Determine  $\sigma_p$  as explained in the statistical introduction. Set  $V = \sigma_p^2$ .

Under the assumption  $N_h \gg 1$  for all strata, we have 
$$n \cong \frac{\sum_{h=1}^L W_h \sqrt{P_h Q_h}}{V + \frac{1}{N} \sum_{h=1}^L W_h P_h Q_h}$$

For moderately-sized  $L$ , the second term in the denominator will be of order not larger than  $\frac{1}{N}$ . So for  $V \gg \frac{1}{N}$ , 
$$n \cong \frac{1}{V} \sum_{h=1}^L W_h \sqrt{P_h Q_h}$$

This latter formula holds for all strata discussed here.

Let  $V(p_h)$  be the sampling variance of  $p$  in stratum  $h$ ,  $h = 1, \dots, L$  and  $V(p_{st})$  be the corresponding sampling variance of  $p$  in the entire population.

Then 
$$V(p_{st}) = \sum_{h=1}^L W_h^2 V(p_h)$$

Since  $V(p) = \frac{PQ}{n} \frac{N-n}{N-1}$ , we have 
$$V(p_{st}) = \sum_{h=1}^L \frac{W_h^2 P_h Q_h}{n_h} \frac{N_h - n_h}{N_h - 1}$$

### M.3.6 CONSTRUCTION OF STRATA

Due to reporting requirements, the states of the United States are clearly strata for a domestic mission. Similarly, significant countries are strata for a global mission. To improve sampling efficiency sometimes it is desirable to stratify the strata themselves. This is the case for the states of the United States, USSR, and Canada. Direct examination of the available data for USSR leads to thirteen strata for the USSR without detailed statistical considerations. More complete data would permit a different and better division of the USSR into strata based on an abstract statistical model.

For each significant state of the U.S. there is enough data to permit use of a model that tends to optimize strata with respect to sampling efficiency. Such a model will now be described.

Recall that a sampling plan is more efficient if it gives a higher confidence level for a fixed number of sample points. This means that the standard error, and hence variance, is lower. So the problem is to minimize  $V(p_{st})$  for fixed  $n$ . An examination of the formulae for  $V(p_{st})$  (of preceding section) shows that  $V(p_{st})$  depends on the number,  $L$ , and choices of the strata. Assume that subpopulations are stratified by a rule that depends only on their proportions  $P_i$ . It can be shown that for optimum choice of boundaries for Neyman allocation  $V(p_{st}) \approx V(p)/L^2$  where  $V(p)$  is the variance that results from random sampling (cf. (5) 5A.7). This implies the larger the number of strata, the better the efficiency. However, if we stratify subpopulations based on an RV other than  $P$  - the one where variance we want to minimize - the picture changes. Suppose  $P' = f(P) + Y$  where  $f(P)$  is linear and  $Y$  is an RV. In the present case,  $P$  could be the proportion today,  $P'$  the proportion last year, and  $Y$  normally distributed. Then, if the correlation coefficient  $\rho$  between  $P$  and  $P' \leq .95$ , it can be shown that little increase in efficiency is likely beyond  $L = 6$ .

When the subpopulations are "farmland counties in a specific state, it isn't clear whether these latter assumptions are met. One difficulty is the assumption  $\rho \leq .95$ . A second is whether  $P \approx P'$ . In that case, the first model is more suitable. Due to the large SU size (16 square miles) and the above considerations, L will generally be chosen to be 6 or less for stratifying states.

We now seek to optimally stratify a set of subpopulations for a fixed L for Neyman allocation. Although an exact formula is available, it is not amenable to computation even on a computer. However, here is an approximation to this method (cf.(5)5A.6). Divide the range of P into equal intervals. If the subpopulations are counties, considering the number of counties in most states, twenty is a good number of intervals. Let the frequency of (i.e., "number of counties in") the  $i^{\text{th}}$  interval to be  $f(i)$  where  $i = 1, \dots, k$  and require that  $i_1 < i_2$  implies P for any county in interval  $i_1$  is less than P for any county in interval  $i_2$ . For each i compute  $\sqrt{f(i)}$ . Let  $\text{Cum}\sqrt{f(i)} = \sum_{j=1}^i \sqrt{f(j)}$ .

Let  $d = \text{Cum}\sqrt{f(k)} / L$ . Then the stratum boundaries on the  $\text{Cum}\sqrt{f(i)}$  scale are  $d, 2d, \dots, (L-1)d$ . A subpopulation belongs to the stratum for which it is first counted in  $\text{Cum}\sqrt{f(i)}$ . (cf.(5) 5A.6 for a detailed example).

This method works well for automatic computation. A less accurate but computationally simpler method can be used for hand calculation. Recall from the previous section that  $V(p_{st}) = \sum_{h=1}^L w_h^2 V(p_h)$ . Hence, minimizing the  $V(p_h)$  will tend to minimize  $V(p_{st})$ . A rough estimate of boundaries that will do this can be gotten graphically. Make a histogram of P versus  $f(P)$ . Divide the abscissa into L intervals so as to minimize the variance of P in each interval. Roughly this can be done by choosing normal-curve shaped clusters or at least clusters (i.e., dense regions) where they exist. Vary L to take advantage of these groupings. The procedure is illustrated in Appendix M.A.



### M.3.7 MULTIPLE CROPS

Most states grow significant quantities of more than one of the seven crops of interest to this study. Washington, for example, grows wheat, corn and barley. From USDA agricultural census data it is possible to estimate the amount of farmland in each county and the proportions of that farmland devoted to various crops. Independent of the choice of  $n$  or  $V(p_{st})$  for a given state and crop, assuming Neyman allocation, one can construct near-optimal strata. The problem is that there will be a different set of strata for each crop in the state. Moreover, assuming Neyman allocation among the states of the U.S., the total number of samples to be assigned to a state will vary depending on the crop. The problem is to develop a sensible procedure to compromise between these various requirements for a domestic multiple crop sampling plan.

The approach used here is based on consideration of net economic return for a given sampling fluctuation error for each crop considered independently at a national level. The process is begun by temporarily assuming that each state is to be randomly sampled. In all of this discussion, "state" means "state farmland", "county" means "county farmland", etc. For each crop, the states are regarded as strata. It can be shown that for Neyman allocation, if the fpc is neglected,  $nx(CV)^2 = \left( \sum_{h=1}^L W_h \sqrt{P_h Q_h} \right)^2 / P^2$  where  $P$  is the fraction of U.S.

farmland planted in the crop. The right-hand side is a constant determined from available data. Call it  $K$ . For U.S. wheat  $K \simeq 4.44$  so  $nx(CV)^2 \simeq 4.44$ . This makes it possible to weigh the cost of increased sample size against the savings that result from greater accuracy. The latter is determined by economic modeling. Assume  $CV$  has been determined for some crop. Then  $n = \frac{\sqrt{4.44}}{CV}$  and

$$n_h = n \frac{W_h \sqrt{P_h Q_h}}{\sum_{i=1}^L W_i \sqrt{P_i Q_i}}$$

Each state is then stratified for each crop as explained in the previous section. Each state now has several sampling plans - one for each of its crops. Fix a state, say Washington. Washington has three crops -- barley, corn and wheat. In order to effect a compromise among the three sampling plans for Washington, it is necessary to have a notion of the relative importance to the nation of each of the crops. Economic benefits are fundamentally determined by national accuracies. State reporting is an additional but less important requirement.

Relative national importance of the crops in a state can be gotten by comparing the percentages of national seeded acreage for each crop in the state. For example, in 1969 Washington acreage in wheat was about 5.3% of the national acreage in wheat, 0.1% of the corn; and 3.8% of the national barley acreage. So in Washington, wheat is of primary importance. Barley is slightly less important. And corn is insignificant. Each crop to be sampled in a state will be classified as primary, major or minor. The primary crop in a state is the one crop whose percentage of national acreage is greatest. A major crop is a non-primary crop whose contribution to national total acreage in that crop is significant. A minor crop is one whose contribution is insignificant. A non-primary crop will be regarded as minor if it contributes less than 1% of the national acreage.

The strata for the primary crop will be used for the compromise plan. The number of samples in each of these strata will be adjusted to approximately meet the accuracy requirements of all major crops. Minor crops will not be considered in the allocation procedure. The result will be that the number of samples allocated to a state will almost always be larger and will never be smaller than the number that would have been allocated for the primary crop alone. Hence, the state and national sample sizes and accuracies will have to be recomputed.

Here are the details of this procedure. A state is divided into counties --- the smallest units for which agricultural data are generally available. Each county belongs to precisely one stratum for each crop. If the effects of large SU's and random fluctuation are ignored, one can compute the fractional number of samples allocated to each county by each sampling plan. If a given county is the  $i^{\text{th}}$  county of the  $h^{\text{th}}$  stratum for the wheat sampling plan, let  $N_{hi}(W)$  be its (farmland) area and  $W_{hi}(W) = N_{hi}(W)/N_h(W)$ , where  $N_h(W) = \sum_i N_{hi}(W)$ , be its weight, or, fraction of stratum  $h$  area. For barley this county is number  $i'$  in stratum  $h'$  and  $W_{h'i'}(B) = N_{h'i'}(B)/N_{h'}(B)$ . Neyman allocation for each crop results in  $n_h(W)$  and  $n_{h'}(B)$  for the respective strata. Then the proportional numbers of samples to be allocated to each county for each sampling plan are  $n_{hi}(W) = W_{hi}(W)n_h(W)$  and  $n_{h'i'}(B) = W_{h'i'}(B)n_{h'}(B)$ . Under the compromise sampling plan, the effective number of samples for this county is  $n'_{hi}(W) = n'_{h'i'}(B) = \max \{ n_{hi}(W), n_{h'i'}(B) \}$ . In general, take  $n'$  for each county to be the max of the  $n$ 's for all non-minor crops. For the resulting sampling plan,  $n'_h = n'_h(W) = \sum_i n'_{hi}(W)$ . Here,  $n'_h$  is the actual number of samples to be allocated to stratum  $h$ , which was one of the primary crop strata. It is now one of the strata for the final sampling plan. Hence,  $h = 1, \dots, L$  defines the strata for every crop in the state. The number of samples allocated to the state is  $n' = \sum_{h=1}^L n'_h$  and the number of samples needed in the nation is just the sum of the numbers needed in each state.

For each crop,  $c$ , the state accuracy is given by

$$V(p_{st}(c)) = \sum_{h=1}^L \left( \frac{(W_h(c))^2 P_h(c) Q_h(c)}{n_h} \times \frac{N_h(c) - n_h}{N_h(c) - 1} \right)$$

The national accuracy is given by

$$V(p_{U.S.}(c)) = \sum_{st} (W_{st}(c))^2 V(p_{st}(c)).$$

If  $V(p)$  is the sampling variance of  $P$  in a population, then the standard error of  $P$  and coefficient of variation are given by  $\sigma_p = \sqrt{V(p)}$  and  $CV = \sigma_p/P$ .

Total area accuracies are given by  $V(Np) = N^2V(p)$ ,  $\sigma_{Np} = N\sigma_p$  and  $CV(Np) = \frac{\sigma_{Np}}{Np} = \frac{N\sigma_p}{Np} = \frac{\sigma_p}{P} = CV(p) = CV$ .

#### M.4 RESULTS

##### M.4.1 CROP MAPS AND CALENDARS

Crop maps and calendars were generated by the TOSS study. Domestically they describe when and where barley, corn, oats, rice, rye, soybeans and wheat grow. The global maps are for wheat only. For each crop there is a map for each month of the year. The maps are colored to show local planting, growth and harvest cycles.

##### M.4.2 SIGNIFICANT CROP PRODUCING AREAS

The following tables show significant crop producing areas in the U.S. and the world.

## SIGNIFICANT CROPS FOR STATES IN JUNE

STATE CODE	STATES	BARLEY	CORN FOR GRAIN	OATS	RICE	RYE	SOY- BEANS	ALL WHEAT WINTER & SPRING	WHEAT WINTER	WHEAT SPRING	DURUM WHEAT	# OF CROPS
01	ALABAMA		619	29			641	85	85			4
02	ALASKA	1.8		1.5								2
04	ARIZONA	144	16					73	73			3
05	ARKANSAS	2	47	68	515		4228	301	301			6
06	CALIFORNIA	1153	194	95	389			355	350			5
08	COLORADO	289	302	93		38		2168	2133	35		5
09	CONNECTICUT											0
10	DELAWARE	20	170	3		8	162	20	20			6
12	FLORIDA		358				169	43	43			3
13	GEORGIA	5	1426	94		72	467	86	86			6
15	HAWAII											0
16	IDAHO	584	28	100		7		1051	822	229		5
17	ILLINOIS	15	9698	703		25	6730	1273	1273			6
18	INDIANA	10	4742	320		21	3311	870	870			6
19	IOWA	4	9514	1840		5	5450	40	40			6
20	KANSAS	165	1236	160		59	852	9849	9849			6
21	KENTUCKY	41	998	19		7	485	183	183			6
22	LOUISIANA		134	28	611		1608	38	38			5
23	MAINE			34								1
24	MARYLAND	99	479	28		15	205	117	117			6
25	MASSACHUSETTS											0
26	MICHIGAN	23	1266	458		40	514	628	628			6
27	MINNESOTA	685	4139	3388		84	3068	828	18	730	80	6
28	MISSISSIPPI		318	50	60		2290	125	125			5
29	MISSOURI	22	2603	170	5.4	16	3150	1035	1035			7
30	MONTANA	1617	6	291		7		3645	2311	1104	230	5
31	NEBRASKA	45	4620	561		150	766	2780	2780			6
32	NEVADA	19		3				11	5	6		3
33	NEW HAMPSHIRE											0
34	NEW JERSEY	20	61	10		10	46	34	34			6
35	NEW MEXICO	14	17					159	159			3
36	NEW YORK	13	247	365		18	5	182	182			6
37	NORTH CAROLINA	55	1281	120		16	885	198	198			6
38	NORTH DAKOTA	2206	123	2511		230	185	6782	96	3905	2781	6
39	OHIO	20	2740	560		16	2344	1067	1067			6
40	OKLAHOMA	422	58	158		49	204	4150	4150			6
41	OREGON	399	10	113		15		788	732	56		5

## SIGNIFICANT HARVESTED ACREAGE BY STATE (CONTINUED)

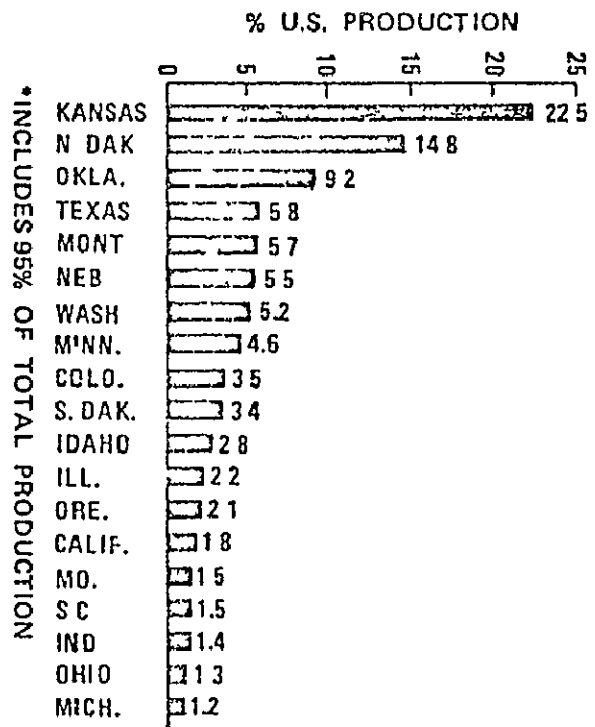
STATE CODE	STATES	BARLEY	CORN FOR GRAIN	OATS	RICE	RYE	SOY- BEANS	ALL WHEAT WINTER & SPRING	WHEAT WINTER	WHEAT SPRING	DURUM WHEAT	# OF CROPS
42	PENNSYLVANIA	191	907	444		16	25	327	327			6
44	RHODE ISLAND											0
45	SOUTH CAROLINA	19	402	83		21	959	82	82			6
46	SOUTH DAKOTA	344	2447	2357		269	243	1963	622	1107	234	6
47	TENNESSEE	17	605	43		6	1193	224	224			6
48	TEXAS	94	571	670	548	38	262	2869	2869			7
49	UTAH	128		22				229	197	32		3
50	VERMONT		74	6								2
51	VIRGINIA	117	432	49		19	361	157	157			6
53	WASHINGTON	370	33	80		36		2472	2177	285		5
54	WEST VIRGINIA	9	49	12				14	14			4
55	WISCONSIN	35	1684	1687		18	174	44	31	13		6
56	WYOMING	116	18	94		15		242	220	22		5
# OF STATES WITH SIGNIFICANT AMT. OF CROP IN JUNE		39	41	42	6	31	30	42				
APPROX. HARVESTED AREA		10 M	55 M	18 M	2.1 M	1.3 M		47.2 M	36.3 M	10.9 M		

NOTE THAT DURING JUNE EVERY KIND OF WHEAT THAT A STATE PLANTS IS IN THE GROUND.

THE ABOVE FIGURES ARE FOR HARVESTED ACREAGE AND AS SUCH ARE SUFFICIENT TO INDICATE WHICH STATES SHOULD BE SAMPLED FOR WHICH CROPS.

CORN FOR GRAIN REPRESENTS 86% OF CORN GROWN FOR ALL PURPOSES.

1973 WHEAT PRODUCTION IN U.S.\*



PERCENT OF 1973 WORLD PRODUCTION BY CROP\*

	WHEAT	CORN	SOYBEANS	RICE	BARLEY	RYE	OATS
USSR	30	4		1	36	37	32
US	13	46	74	1	6	2	19
China	8	8	12	33	5		2
India	7	2		21	2		
France	5	3			7	1	5
Canada	5	1	1		7	1	9
Australia	3				2		2
Italy	2	2					1
Turkey	2	.3			2	2	1
Pakistan	2			1			
West Germany	2				4	9	7
Argentina	2	3	.5			2	1
Poland	2				2	29	6
Romania	1	3					
UK	1				6		2
Yugoslavia	1	3					1
Czechoslovakia	1	.2			2	2	1
Hungary	1	2			1	1	
Iran	1						
Spain	1	1			3	1	1
Afghanistan	1						
Bulgaria	1	1					
Mexico	1	3	1				
Morocco	1						
Brazil	1	5	8	2			
Egypt	1	1		1			
South Africa	.5	4					
Indonesia		1	1	7			
Thailand		1		5			
Phillippines		1		2			
Bengladesh				6			
Japan			.2	5			
Burma				3			
Korea			.4	2	1		
S. Vietnam				2			
N. Vietnam				1			
Denmark							1
East Germany					2	6	1
Austria		.3				2	1
Sweden	.4					1	2
Finland					1		2
Norway							1

\*Taken from Agricultural Statistics 1974 by USDA.



#### M.4.3 THE RELATIONSHIP BETWEEN SAMPLE SIZE AND ACCURACY

In sampling for proportions, there is an extremely useful relationship between sample size and coefficient of variation. It holds both for random sampling for proportions and for Neyman allocation with negligible finite population correction in sampling for proportions:

$$n \times (CV)^2 = K, \quad K = \text{Constant}$$

In the random sampling case,  $K = Q/P$ . In the case of stratified random sampling with Neyman allocation,

$$K = \left( \sum_{h=1}^L w_h \sqrt{p_h q_h} \right)^2 / P^2$$

Here are the significant values of  $K$  for wheat for Neyman allocation in this study:

Case 1. World wheat for following ten countries each sampled at random internally within the best available estimate of their farming regions: USSR, UK, Canada, Argentina, Australia, Spain, France, Italy, India, South Africa.

$$K_G = 1.8931$$

Case 2. USSR stratified into the thirteen regions: Baltic, Belo-Russia, Central, Central Asia, Central Chernozem, Kazakhstan, North Caucasus, Northwest, Trans-Caucasus, Ukraine, Ural, Volga, Volga Vyatka. These regions are indicated on the accompanying map.

$$K_{\text{USSR}} = 2.1270$$

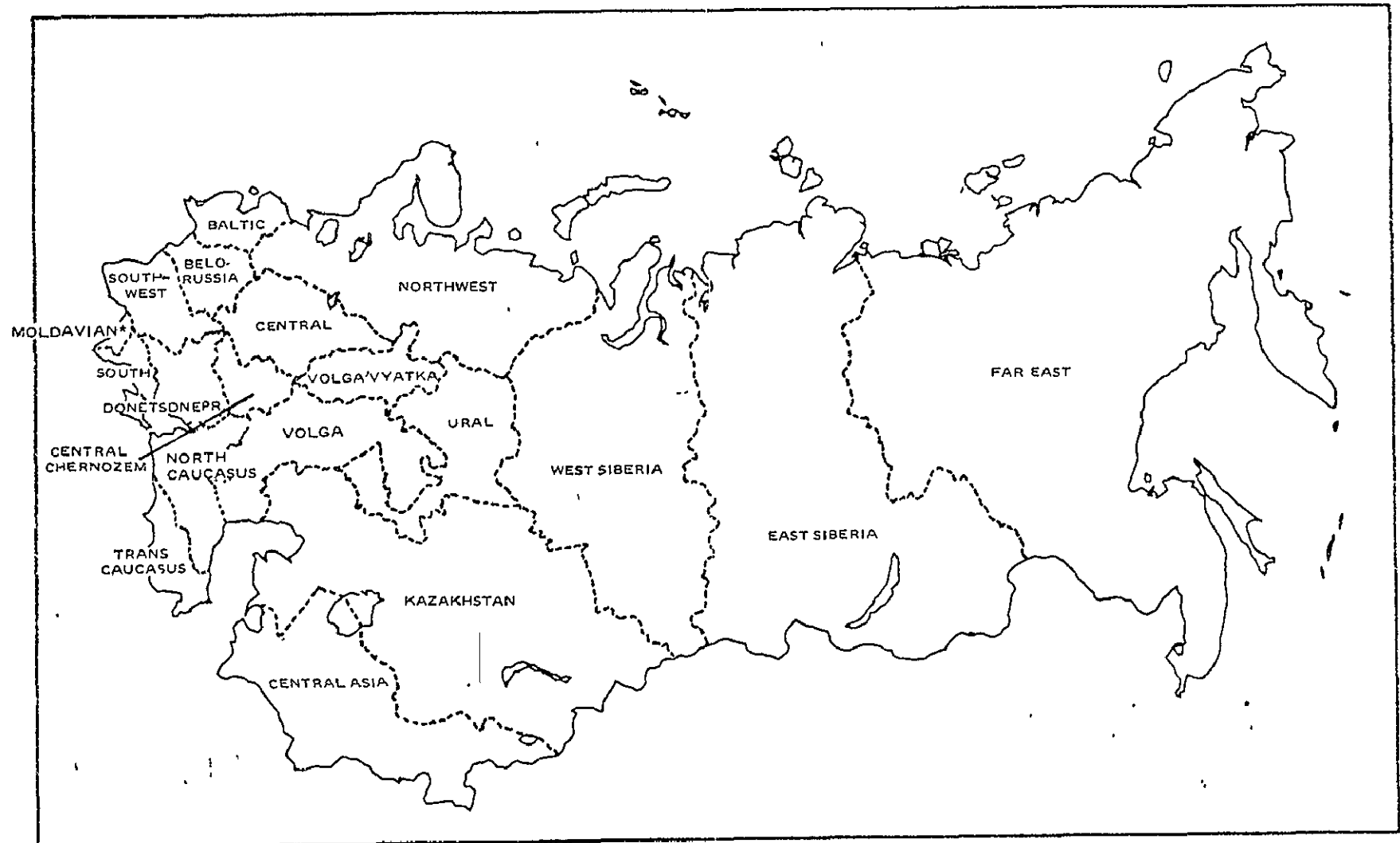
Case 3. U.S. Stratified into 40 coterminous states with significant production. Farmland of individual states sampled at random.

$$K_{\text{US}} = 4.4414$$

Case 4. Washington state with three strata:

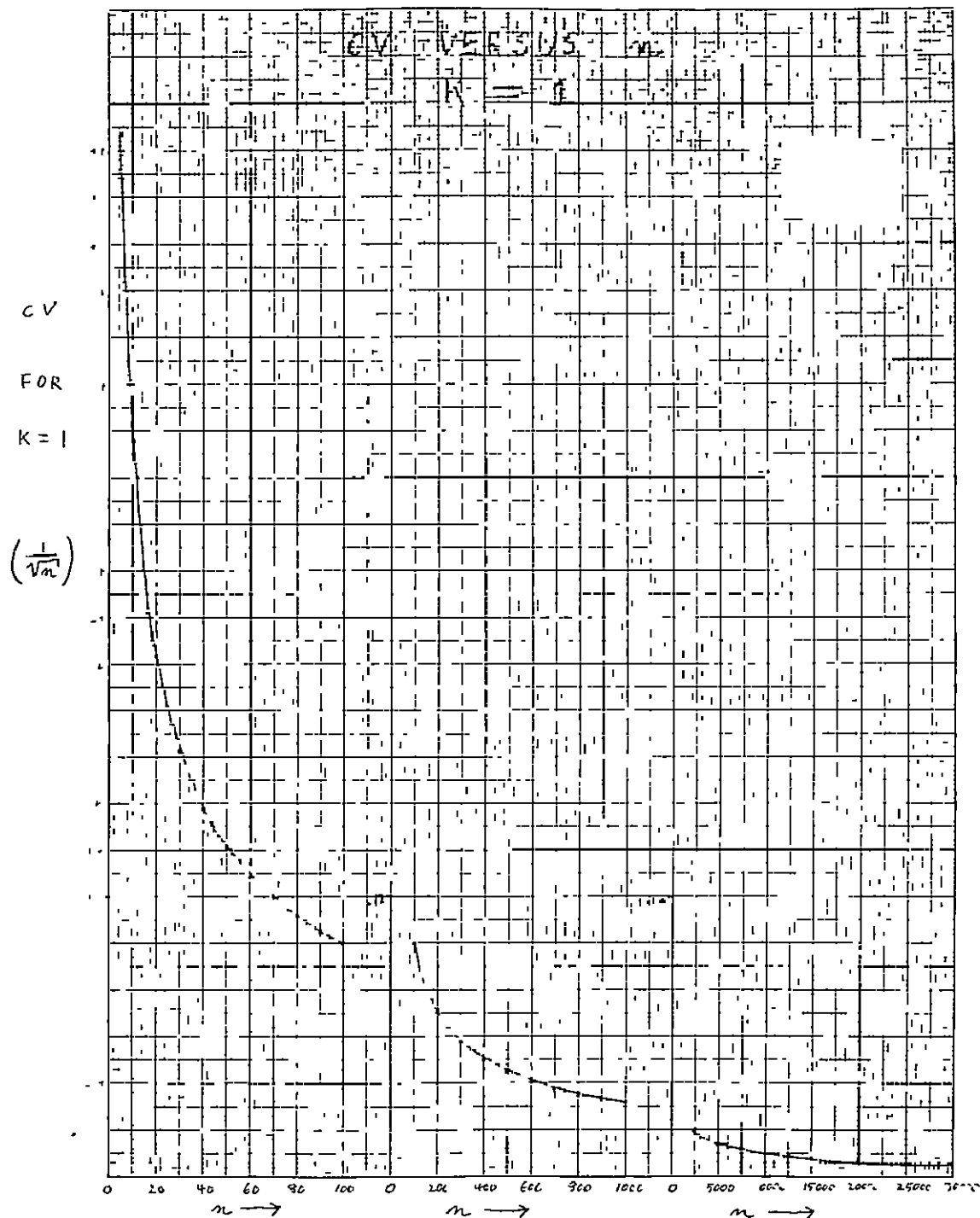
$$K_W = 1.2743$$

ECONOMIC REGIONS: USSR



Since  $n \times (CV)^2 = K$  can be written in the form  $CV = \frac{1}{n} \times \sqrt{K}$ , the equation  $CV = \frac{1}{\sqrt{n}}$  may be regarded as a normalized form of the more general equation.

The graph of  $\frac{1}{\sqrt{n}}$  versus  $n$  follows. To get CV for any  $n$  and  $K$ , multiply the ordinate  $1/\sqrt{n}$  by the constant  $\sqrt{K}$ .



#### M.4.4 WORLD WHEAT SAMPLING PLAN FOR 50,000 SAMPLES

The plan is to set aside 30,000 samples for the eleven most significant countries for wheat. The other 20,000 samples are to be spread around the rest of the world using Neyman allocation. The following table shows the results for the eleven assuming random allocation. Results for stratification of the U.S. into states and the USSR into thirteen regions are also presented. The state of Washington is presented in an appendix as an example of the calculations involved. By improving the sampling area frame for the United States, one can do appreciably better than the United States results would indicate. A much finer sampling area frame is now available from U.S.D.A. Note that the U.S. results presented are with states unstratified.

#### WHEAT SAMPLING PLAN FOR ELEVEN NATIONS WITH 30,000 SAMPLES

<u>Country</u>	<u>Farmland*</u>	<u>%Wheatland</u>	<u><math>n_h/n</math></u>	<u><math>n_h</math></u>	<u><math>CV_U^*</math></u>	<u><math>CV_S^*</math></u>
Argentina	19660	.20346	.03499	873	.067	
Australia	25360	.24338	.06708	1674	.043	
Canada	41889	.23917	.07898	1970	.040	
France	21016	.18776	.03629	905	.069	
India	162093	.12265	.23505	5864	.035	
Italy	15301	.23652	.02874	717	.067	
South Africa	12088	.16752	.01996	498	.100	
Spain	20592	.15249	.03274	817	.082	
UK	7055	.16371	.01153	288	.133	
USSR	230720	.27349	.45464	11342	.015	.014
USA	384714000	.14109	---	5052	.035	.030

\* Farmland is in thousands of hectares except for the U.S., which is in acres. For the first nine nations, it is just arable land. For USSR, agricultural land for the regions of interest is used (cf Ref. 9). Figures for the U.S.A. are cropland excluding pasture (cf. P. 507 of (2)). The ten nations excluding U.S.A. require 24948 samples. As an aggregate, the ten nations have  $CV \approx .0120$  if USSR is unstratified and  $CV = .0116$  if USSR is stratified.  $CV_U$  is CV for a country unstratified internally.  $CV_S$  is CV for a country when it is internally stratified.

# Wheat Sampling Plan for the United States with 5000 Samples

## States Internally Unstratified

$$K = 4.4414$$

State	Farmland (thousands of acres)	% Wheatland to Farmland	$n_h/n$	$n_h$	CV
AL	3728	3.2	.00578	29	1.02
AZ	1539	5.3	.00299	15	1.10
AR	7492	5.1	.01436	72	.51
CA	9401	4.1	.01638	82	.53
CO	10108	30.8	.04080	204	.10
DE	506	4.3	.00091	5	2.19
FL	2826	1.9	.00340	17	1.74
GA	5312	1.8	.00626	31	1.30
ID	5237	22.3	.01904	95	.19
IL	23291	5.7	.04725	236	.26
IN	12674	7.3	.02882	144	.30
IA	24451	0.2	.00965	48	3.18
KS	28965	37.2	.12235	612	.05
KY	5107	4.8	.00948	47	.65
LA	4284	1.9	.00515	26	1.41
MD	1661	7.6	.00383	19	.80
MI	7903	8.6	.01937	97	.33
MN	21762	3.9	.03666	183	.37
MS	5833	2.6	.00814	41	.96
MO	14013	8.5	.03414	171	.25
MT	14935	25.5	.05690	285	.10
NB	21313	14.2	.06508	325	.14
NV	587	2.2	.00077	4	3.39
NJ	629	7.6	.00145	7	1.29
NM	1897	15.2	.00595	30	.43
NY	5141	3.8	.00861	43	.77
NC	5389	4.2	.00945	47	.69
ND	27930	24.8	.10550	528	.08
OH	10807	10.2	.02862	143	.25
OK	10749	49.3	.04698	235	.07
OR	4241	19.7	.01473	74	.24
PA	5068	6.8	.01113	56	.50
SC	2969	3.0	.00441	22	1.22
SD	17995	12.1	.05139	257	.17
TN	5201	5.2	.01016	51	.60
TX	28016	14.7	.08677	434	.12
UT	1489	16.3	.00481	24	.46
VA	3213	5.4	.00632	32	.75
WA	7651	37.8	.03242	162	.10
WV	877	1.9	.00104	5	3.12
WI	10258	0.4	.00605	30	2.68
WY	2293	12.8	.00669	33	.45

Wheat Sampling Plan for USSR with 11342  
Samples

$$K = 2.1270$$

Stratum	Farmland (1000's HA)	% Wheatland to Farmland	$n_h/n$	$n_h$	CV
Baltic	5140	5.4	.0154	175	.32
Belo-Russia	6218	6.6	.0207	235	.24
Central	13984	12.4	.0613	695	.10
Central Asia	6554	17.6	.0333	378	.11
Central Chernozem	11176	16.1	.0548	622	.09
Kazakhstan	31097	56.7	.2055	2331	.02
North Caucasus	15985	26.8	.0943	1070	.05
Northwest	2937	4.3	.0080	91	.50
Trans-Caucasus	2977	21.0	.0162	184	.14
Ukraine	34312	19.6	.1817	2061	.04
Ural	15920	41.5	.1047	1188	.03
Volga	27891	33.0	.1751	1986	.03
Volga Vyatka	6624	12.3	.0290	329	.15

## APPENDIX M.A.

### STRATA CONSTRUCTION FOR WASHINGTON STATE

The following tables show the construction of strata for wheat in Washington with 162 samples to be allocated among 7,651,000 acres of farmland in Washington. The data used are derived from the 1969 USDA Agricultural census.



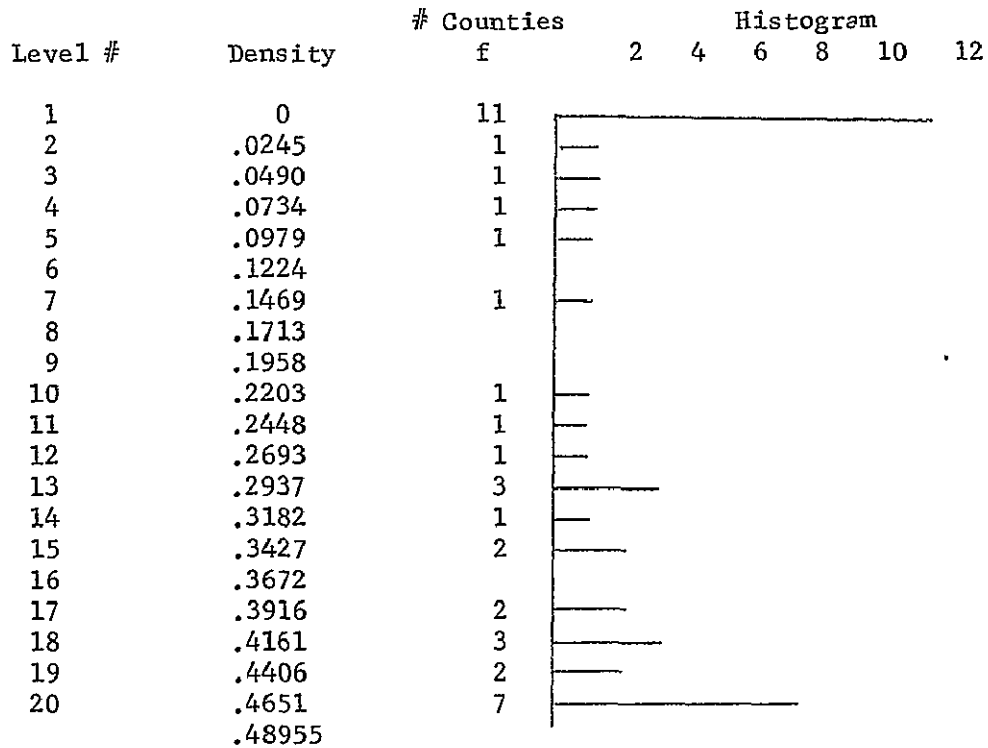
## WASHINGTON STATE

## PARTITIONING COUNTIES INTO STRATA FOR WHEAT

FIPS County Code	Acres of Wheat	Acres of Farmland	County Wheat Densities	Level #	Stratum #
1	537000	1126877.6	.476538	20	3
3	36500	88059.1	.414494	17	3
5	217000	470907.2	.460813	19	3
7	3000	6162.1	.486847	20	3
9	30	556.6	.053899	3	1
11	950	11926.7	.079653	4	1
13	107100	233167.7	.459327	19	3
15	10	616.2	.016228	1	1
17	264300	539883.5	.489550	20	3
19	1300	4373.1	.297272	13	2
21	146600	344086.3	.426056	18	3
23	93400	223626.3	.417661	18	3
25	206400	491182.7	.420210	18	3
27	10	1113.2	.008983	1	1
29	700	2186.6	.320132	14	2
31		198.8	0	1	1
33		3677.4	0	1	1
35		298.2	0	1	1
37	7500	21269.3	.352621	15	2
39	76100	162402.4	.468589	20	3
41	690	3061.2	.225402	10	2
43	494000	1051341.6	.469876	20	3
45		596.3	0	1	1
47	16400	34985.1	.468771	20	3
49		198.8	0	1	1
51	300	1789.0	.167691	7	1
53		1192.6	0	1	1
55	360	1212.6	.296883	13	2
57	6430	25503.3	.252124	11	2
59		198.8	0	1	1
61	100	5963.4	.016769	1	1
63	200000	546443.2	.366003	15	2
65	14700	52080.1	.282258	12	2
67	80	755.4	.105904	5	1
69		596.3	0	1	1
71	280200	573079.5	.488937	20	3
73	340	11310.5	.030061	2	1
75	582000	1435978.8	.405298	17	3
77	51500	172142.5	.299171	13	2

WASHINGTON STATE  
HISTOGRAM FOR CHOOSING WHEAT STRATA

$$.48955006/20 = .02447750302 = \Delta \text{ for histogram}$$



3 strata with density ranges of

1:  $[0, .1958)$  with 16 counties

2:  $[.1958, .3672)$  with 9 counties

3:  $[.3672, .4896)$  with 14 counties

## WASHINGTON STATE

## ALLOCATING SAMPLES TO WHEAT STRATA

STRATUM	COUNTY NUMBERS
1	9, 11, 15, 27, 31, 33, 35, 45, 49, 51, 53, 59, 61, 67, 69, 73
2	19, 29, 37, 41, 55, 57, 63, 65, 67
3	1, 3, 5, 7, 13, 17, 21, 23, 25, 39, 43, 47, 71, 75

STRATUM	$A_h$	$N_h$	$P_h$	$\sqrt{P_h Q_h}$	$W_h$
1	1820	40988.2	.04440302	.2059888	.00535723
2	283180	828271.9	.3418925597	.4743438	.108256685
3	3060000	6781739.9	.4512116426	.4976140	.88638608

STRATUM	$W_h \sqrt{P_h Q_h}$	$n_h/n$	$n_h$
1	.001103529	.00223598	.362
2	.0513508870	.1040476	16.856
3	.4410781257	.8937164	144.782

$$\Sigma = 162$$

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## **APPENDIX N**

### **THEMATIC MAPPER CHARACTERISTICS**

## APPENDIX N

### THEMATIC MAPPER CHARACTERISTICS

This appendix provides a brief summary of the characteristics of the Thematic Mapper sensor by reproducing excerpts from the Landsat-D Thematic Mapper Technical Working Group Final Report published by NASA/JSC, June, 1975 (JSC-09797). This report is the result of a working group meeting held at Purdue University on April 30, May 1 and 2, 1975 and represents the best baseline definition of the Thematic Mapper.

## 1

## INTRODUCTION

This report describes the results of the LANDSAT-D Thematic Mapper Technical Working Group Meeting held at Purdue University on April 30, May 1 and 2, 1975. The Thematic Mapper is a second generation earth resources scanner having significantly advanced characteristics over that of the current and exceptionally successful MSS (Multispectral Scanner) used in the LANDSAT series. This new instrument is planned for spacecraft launch in 1980.

Several previous meetings, plus a significant amount of research, have been useful in delineating preliminary performance specifications for the Thematic Mapper. The purpose of this meeting was to make final technical recommendations on these specifications prior to the final design and development phase of the flight hardware being undertaken by NASA. A group of 40 scientists and engineers from government, industry and the universities were invited. Selection of the invitees was based upon experience and specific expertise in sensor system design, data processing (preprocessing and information extraction), and various earth resources disciplines. Organization and membership of the group is contained in Appendix C.

The tone and thrust of the meeting was established by Mr. William E. Stoney, Director, Earth Observation Programs in his opening remarks. These remarks are contained in their entirety in Appendix A.

The group was charged to provide and substantiate recommendations for the Thematic Mapper specifications based on:

- a. The detailed Mission Objectives (See Appendix B)
- b. Performance criteria (the classification accuracy of a machine data analysis system when utilized in vegetative mapping tasks)
- c. Instrument and System related constraints (See Appendix D)

During the meeting, briefings were given to provide the participants with further background detail, after which deliberations were conducted by four sub-groups. A more detailed scenario of the meeting organization is presented in Appendix C.

The resulting recommendations, and the program elements deemed in need of further research are presented in Section 2 of this report. These recommendations were synthesized from four individual subgroup reports on the final day of the meeting. They were documented into this form by the editors and reviewed by the Consolidation Panel for correctness.

The recommendations made are based both upon specific documented results, which are referenced in the subgroup reports, and upon the combined engineering judgments of the group members. These judgments are the results of knowledge derived from many references and years of research. Section 3 contains an edited bibliography of such research results.



## RECOMMENDATIONS AND CONCLUSIONS

The Thematic Mapper Technical Working Group has concluded the following:

### A. Instrument and Orbit Parameters

#### 1. Spectral Bands

The recommended spectral bands are located in those areas of the spectrum where maximum discrimination of vegetation type and condition can be expected. The bands have been narrowed to take advantage of such important features as the chlorophyll absorption region of green vegetation.

For a given application, fewer than six bands have been shown to be sufficient for maximum classification accuracy; but the same three or four bands will not be optimum for any given time, place, or specific application. Therefore, it is critical that as many regions of the spectrum as possible be included. Seven spectral bands have been recommended, as follows:

<u>Band</u>	<u>Value/Comments</u>
0.45-0.52 $\mu$ m	<ol style="list-style-type: none"> <li>1. Land use mapping, Soil/vegetation differences, deciduous/coniferous differentiation.</li> <li>2. While this band's greatest value is perhaps in hydrological studies, it is believed to have value for vegetative studies as well. However, if a seven band system is not feasible, this band should be the first considered for deletion.</li> </ol>
0.52-0.60	<ol style="list-style-type: none"> <li>1. Important indicator of green reflectance for assessment of growth stage and vegetation vigor.</li> <li>2. Desirable to keep this band as narrow as possible around the green peak without unduly sacrificing signal.</li> </ol>
0.63-0.69	<ol style="list-style-type: none"> <li>1. Chlorophyll absorption for species differentiation.</li> <li>2. Lower end of band can be shifted</li> </ol>

	to 0.61 if sensor design dictates; upper end is critical and should not be shifted.
0.74-0.80	<ol style="list-style-type: none"> <li>1. Sensitive vegetation studies, including biomass and stress.</li> <li>2. Keep band as narrow as possible around the vegetation reflectance shoulder.</li> </ol>
.80-0.91	<ol style="list-style-type: none"> <li>1. High vegetative reflectance, species identification and water body delineation.</li> <li>2. 0.91<math>\mu</math>m is critical and should be the upper limit to avoid water absorption band.</li> </ol>
1.55-1.75	<ol style="list-style-type: none"> <li>1. Vegetation moisture conditions; snow/cloud differentiation.</li> <li>2. This band width should be maintained to avoid the water absorption band.</li> </ol>
10.4-12.5	<ol style="list-style-type: none"> <li>1. Temperature variations and characteristics; vegetation density and cover-type identification.</li> <li>2. The lower end of the band is critical to avoid the ozone absorption band; upper limit fixed to avoid the carbon dioxide absorption band.</li> </ol>

## 2. Sensitivity

NE $\Delta\rho$  of 0.005 @ 13% reflectance for total system in all visible/NIR bands for range of reflectances associated with vegetation problems.

NEAT of 0.5 K @ 300°K for total system, including atmospheric attenuation.

There is evidence that improved radiometric resolution is as important as spectral resolution in applications requiring more difficult discrimination and where numerical models are to be applied.

## 3. Spatial Resolution

30-40 meters, with spectral and radiometric resolution having higher priority. To accommodate working with the large percentage of agriculture plots of 20 acres and less, the design goal should be a 30 meter IFOV. Appropriate

trade-offs can be made to maintain the spectral and radiometric requirements, recognizing that IFOV should not be treated lightly in a "whatever results" manner.

#### 4. Dynamic Range

The general recommendation was that the design philosophy used in LANDSAT proved to be a wise choice and should be used in the Thematic Mapper to the extent possible. Reflecting this philosophy, specifications for each band are as follows:

<u>Band</u>	<u>Surface Reflectance for Saturation</u>
0.45-0.52	20%
0.52-0.60	58%
0.63-0.69	53%
0.74-0.80	75%
0.80-0.91	75%
1.55-1.75	50%
10.4-12.5	270-330 K

#### 5. Geometric Accuracy

Registration of pixels between scenes to within 0.5 pixel (rms) after ground processing, is required. This level of accuracy is needed to achieve the classification accuracies required by the user when the data is processed in the multitemporal mode.

#### 6. Temporal Resolution

A 9-day repeat cycle, using 2 satellites, was recommended. Obtaining 9-day repeat with 2 sensors on the same satellite is not desirable for the following reasons:

- a. The atmospheric variabilities will be increased with the larger cant angles.
- b. The terrain effect on geometric error will be increased. In the nadir scan system (single scanner) the terrain error will vary from 0 at nadir to 15 meters error at the swath edge for a 100 meter difference in terrain elevation. In the offset scan system (2 scanners) the terrain error will vary across the swath from 15 meters to 30 meters for a 100 meter difference in terrain elevation.

#### 7. Scanning Method

Rectilinear scanning is preferred over conical scanning for the following reasons:

- a. Conical scanning would make direct read-out capability more compli-

plicated and probably considerably more expensive.

- b. The conical scan provides a constant atmospheric path, but it views the terrain at varying scan angles and aspect with respect to crop rows and other regular terrain patterns introducing data variances that are not well understood.
- c. Terrain effects on geometric accuracy are less on the average for the rectilinear scanning method, since in this case for a portion of each scan the system is looking at or near nadir.

All group members were in agreement that the data should be delivered in rectilinear form.

#### 8. Thermal Band Resolution

Thermal data at the same spatial resolution as the other bands would be ideal, but the panel members accepted resolution of 120-meter for this band because of system design constraints. It is recommended that this band's resolution be an odd multiple, e.g. 3X or 5X, of the other bands. This will provide for convenient registering or centering the thermal band on the other bands in performing classification and overlaying the image.

#### 9. Atmospheric Effects

Since the atmospheric effect is not an instrument parameter, an attempt was made to consider such effects only as they relate to other sensor parameters. Specific comments on atmospheric effects are found in the individual subgroup reports.

### B. Areas for Further Study

- 1. The group was not convinced that a spatial sampling rate of 1.4 IFOV (along scan line) is appropriate or necessary.

Since the sampling scheme will obviously have an effect on the data rate and ground station throughput considerations, the group recommends further study to optimize the sampling scheme for the total system, which includes data acquisition and processing.

- 2. It is apparent that there has been no coordinated program to collect, analyze and interpret the spectral data on a multidisciplinary basis to optimize channel selection for future satellites. Therefore, it is recommended that such a coordinated program be undertaken as soon as possible so that the results may have a significant impact on the shuttle era scanner systems and proposed aircraft multispectral scanner systems.

3. It is recommended that cloud cover build up during the day be studied carefully for the agricultural areas of high interest to determine the optimum time for data acquisition. Optimum time for thermal data acquisition must be considered in conjunction with the cloud cover.

4. The LANDSAT operational system should be thoroughly integrated with the needs of central data processing, regional data centers, and small low-cost data centers to provide maximum efficiency and economy in utilization by state, regional, and foreign users. Rapid turn-around requirements need to be established and assessed.

5. For a given classification task, errors arise in classification due to statistical variability in the scene (including the atmosphere) and statistical variability occurring in the sensor system and data stream. Examples of the latter are detector noise and quantization error. Errors are also introduced due to the finite IFOV. Studies should be conducted to assess quantitatively the relative sensitivity of classifier performance to these system parameters, and to define methods to compensate for them.

6. It was observed during the meeting that although a large dynamic range is necessary in the data system to handle data gathered at various sun angles, the entire range may not be necessary for any given sun angle. Thus an on-board gain or digitization changing scheme may be useful in reducing the number of bits which must be transmitted, without sacrificing data quality. The feasibility of this possibility should be investigated.

## 3

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- A. Spectral Band Selection
- B. Sensitivity
- C. Spatial Resolution
- D. Dynamic Range
- E. Geometric Accuracy
- F. Temporal Resolution
- G. Scanning Method
- H. Atmospheric Effects
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**APPENDIX O**  
**TOSS DATA HANDLING (TRACKING AND DATE RELAY**  
**SATELLITE AND DOMSAT RETRANSMISSION)**

APPENDIX 0

TOSS DATA HANDLING

(TRACKING AND DATA RELAY SATELLITE AND DOMSAT RETRANSMISSION)

This appendix presents key considerations on data generated by Thematic Mapper and Multispectral Scanner sensors on Landsat type spacecraft, the transmission of the sensor data to the earth via the Tracking and Data Relay Satellite System (TDRSS), and data processing and dissemination by ground stations interconnected through a Domsat type network.

The TOSS study considers Landsat type vehicles with sensors of the Thematic Mapper (TM) and/or Multispectral Scanner (MSS) types. The data rates of 100 and 15 Mbps, respectively, and the requirement for real-time data dissemination, indicate the need for using the TDRSS (Tracking and Data Relay Satellite System) to transfer the data to the earth, and a Domsat to distribute the data to the various users on the earth. The data will first be delivered from the TDRSS ground station to a central processing center, and then the processed data will be distributed to individual users.

The Landsat type vehicle will have a Ku-band transponder incorporating the features required for functioning with the TDRS transponders; typically, a 3.81 meter diameter antenna (12.5 feet) will require 11.2 watts output for a 100 Mbps data rate, and increasing or decreasing directly with data rate change. The TDRSS will have two satellites spaced  $130^{\circ}$  apart near the equatorial plane, which results in a small coverage gap at  $75^{\circ}$  longitude, over India; however, the gap is small for the Landsat S/C at a 926 km (500 nm.) altitude. The two TDRS vehicles can handle a total of four 100 Mbps channels (e.g., four Landsats with one TM each) or three 100 Mbps and one 300 Mbps channels (e.g., two Landsats with two sensors, TM or MSS, each).

Relative cost factors for the various alternatives would constitute a relatively extensive study. However, the TDRSS costs will be the same for either the TM at 100 Mbps or the MSS at 15 Mbps, assuming that a complete TDRSS channel would be tied up in either case. Domsat costs, which vary with bandwidth, are directly related to data rate unless a

complete channel is reserved, whether used or not, by NASA. The value of the extra Domsat bandwidth costs is ultimately to be related to the value of the extra bandwidth to the users.

## 0.1 OBJECTIVES

### 0.1.1 PURPOSE

The TERSSE Operational System Study (TOSS) involves a Landsat type spacecraft using earth mapping sensors of very high data rates to achieve high mapping accuracies and resolutions. Specifically, Thematic Mappers will be employed which generate data at about 100 Mbps; in addition, other sensors, particularly the Multispectral Scanner (MSS), may be included and housekeeping data will be involved. Real time sensor data delivery is to be implemented. To accomplish this objective, the Tracking and Data Relay Satellite System (TDRSS)\* is to be used to transfer the high-rate data to the earth in real time, and communications links involving Domsats will be employed to route the data to processing centers and to distribute the data to users. The subject study will consider the total data handling requirements in the overall system, various system configurations possible, and the equipment that would be required.

## 1.2 FUNCTIONAL REQUIREMENTS

The data handling system for the Landsat type spacecraft is considered in terms of up to four S/C operating simultaneously, and up to two TDRS's with channel capacities as currently defined in the TDRSS User's Guide.

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\*TDRSS - Tracking and Data Relay Satellite System  
TDRS - Tracking and Data Relay Satellite



Sensors on the S/C may be either or both the Thematic Mapper (TM) and Multispectral Scanner (MSS); each S/C may also have more than one sensor, possibly operating simultaneously. Specified data rates for the TM and MSS are, respectively, 100 and 15 Mbps. Housekeeping data are at a relatively low rate and can be assumed to be includable in either of the specified rates. A general block diagram in Figure 0-1 shows the general relation of the Landsat vehicles and the TDRS as a data relay to transfer the data to the ground users. Note that the user Landsats will be in polar orbits while the TDRS's are in nearly equatorial synchronous orbits.

The TOSS requirement is to provide real-time data to user ground stations (through appropriate relays) from the appropriate sensors in the user S/C's. The data rates available with the TDRSS are:

- 2 channels of up to 100 Mbps data each,
- or 1 channel of up to 300 Mbps data, plus 1 channel of 100 Mbps.

For two TDRS relays, the rates are:

- 4 channels of up to 100 Mbps each,
- or 3 channels of 100 Mbps plus 1 channel of 300 Mbps.

Data required to be relayed to the ground stations may include:

- Thematic Mapper (TM): 100 Mbps each;
- Multispectral Scanner (MSS): 15 Mbps each;
- Compacted TM data (for on-board tape storage): 15 Mbps (EOS\* data).

The last mentioned mode is included only as a potential technique over part of the earth where the TDRS's are not visible to a Landsat S/C

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\* Earth Observatory Satellite - System Definition Study; Document Number 74SD4249, General Electric Company

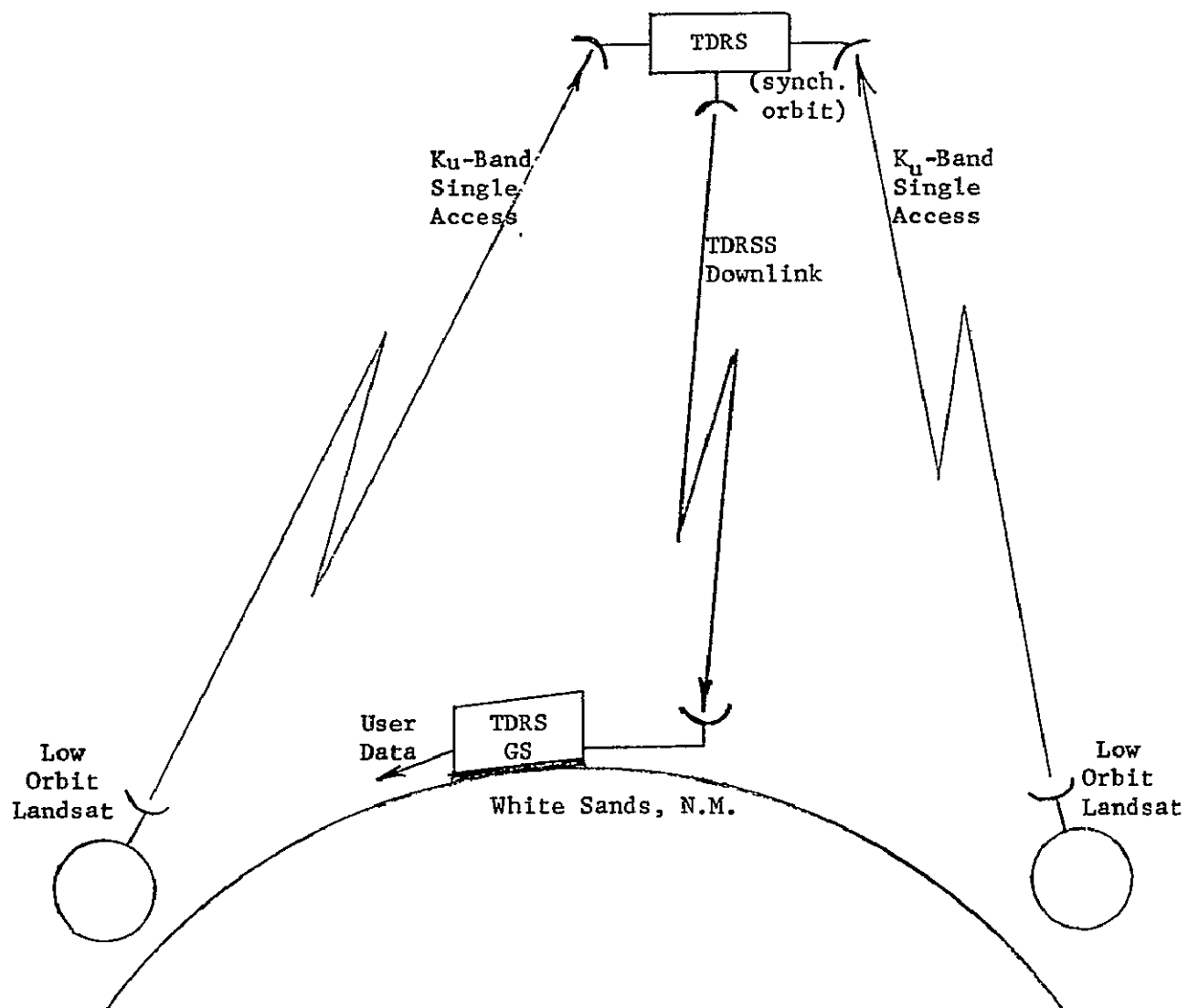


FIGURE 0-1. LANDSAT S/C AND TDRSS DATA TRANSFER CONFIGURATION FOR TOSS

and real-time data are impossible.

The data dissemination will require the use of a Domsat for further relaying of the wideband data to the user ground stations. Ground transmission lines are expected to be limited to 1 or 2 Mbps (per TDRSS study). Data will have to be reformatted since the Domsats have 12 (or 24 in some future systems) independent channels of 36 MHz bandwidth each, spaced on 40 MHz centers. Also, modulations must be compatible; the proposed Domsat B will use BPSK in its Ku-bands and QPSK in its C-bands. A number of the Domsat channels thus may be used simultaneously, with the input data divided with  $1/N$  going through each of the  $N$  channels, isolation filters between channels would preclude simple transmission of the wideband data.

The Landsat S/C's are to operate over a period of several years. The TDRS's will essentially have to be dedicated to the S/C's during those times (data takes) that data are to be relayed to the ground, and appropriate scheduling of the entire system will be required, including the Domsat channels and all ground distribution and processing equipment required. In this way, the very high quality data of the TM's can be delivered without delay to preserve the timeliness of the data.

## 0.2 DESCRIPTION OF SYSTEM

### 0.2.1 GENERAL DESCRIPTION

#### 0.2.1.1 Elements of System

The entire TOSS incorporates the following elements:

- . 1 to 4 spacecraft (Landsat type) with 1 or 2 each TM's and/or MSS's
- . 2 TDRS's
- . The TDRSS ground station (White Sands, N. M.)
- . Data interface to a Domsat ground station (also at White Sands)
- . A Domsat
- . A TOSS Data Processing Center (location TBD but at or near a Domsat ground station)
- . A storage-type ground station (Sioux Falls, S. D., at or near the Domsat ground station)
- . Domsat stations as required for user data reception

The diagram of Figure 0-2 shows the elements and their interfacing.

#### 0.2.1.2 Interfacing with Related Programs

TOSS incorporates, or is a part of, other programs on which its eventual parameters and specifications will be dependent. The two major programs are indicated in Figure 0-2; the TDRSS is required for real-time wideband data transfer from the S/C to a ground station; and the Domsat is necessary to relay wideband data from the White Sands TDRSS ground station to distant processing and user stations. Brief general information on some of the related programs is given below.

TDRSS: The system will use two synchronous satellites to receive data from low altitude satellites, and relay the data to a ground station at White Sands, N. M. Data from user satellites may be transferred on either S-band or Ku-band links, but only the latter are wideband enough for the TOSS purpose. The TDRS's are located at about 40°W and 170°W, which results in a small area not covered by either, centered on 75°E;

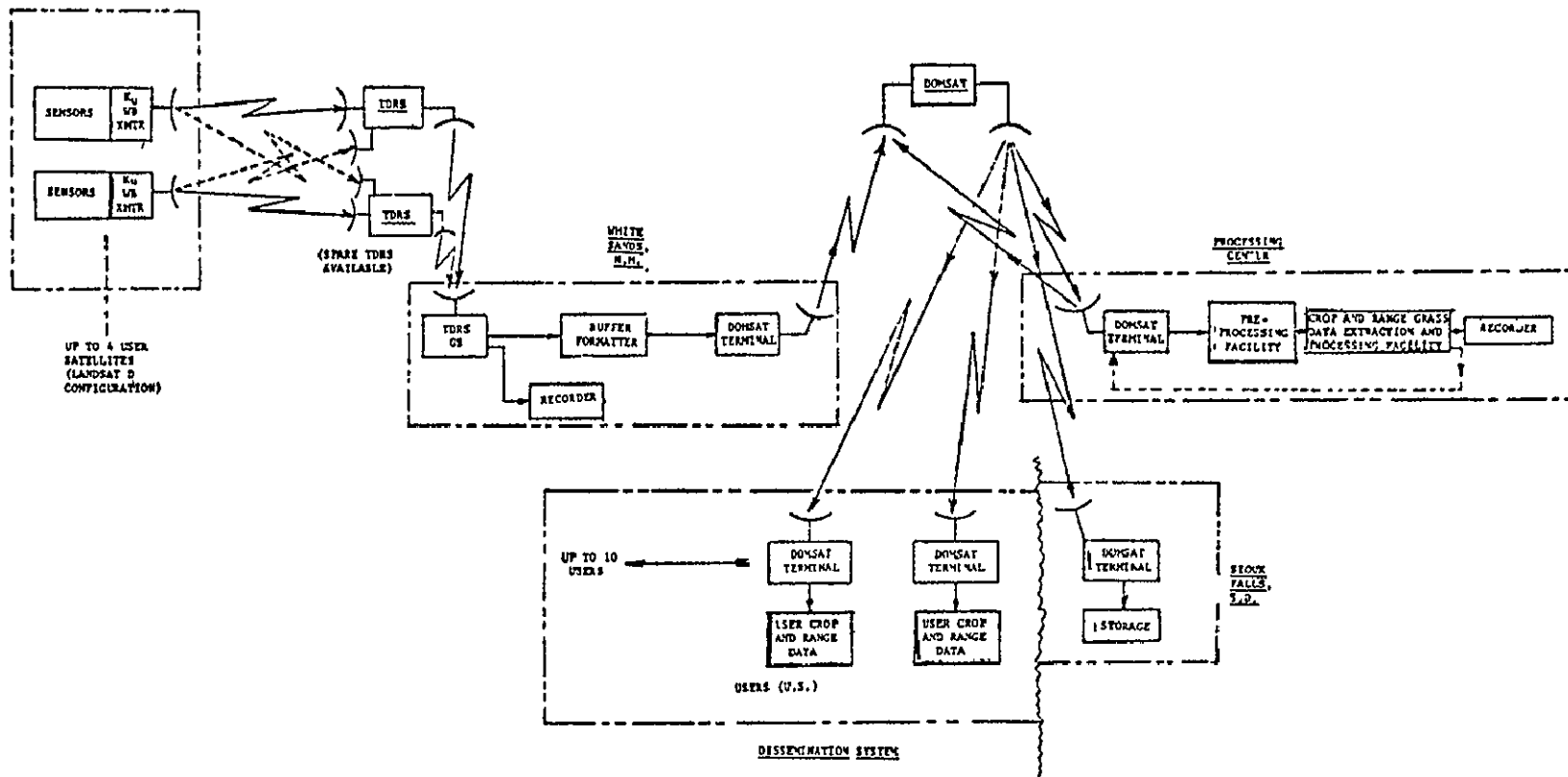


Figure 0-2 TOP LEVEL DISSEMINATION SYSTEM

the extent of the area varies with user S/C altitude, and becomes essentially zero above 1200 km. The TDRS Ku-band transponder follows an acquisition procedure with the user S/C, each being required to track the other. Data are subsequently transferred to the ground station over a Ku-band link; each TDRS has a separate ground receiving subsystem. The data are reformatted and transmitted via the NASCOM interface to a nearby Domsat ground station. The TDRSS is also capable of transmitting commands to the user S/C.

The TDRSS can handle "single access" data from three TDRS's simultaneously (two active, one spare), and can operate with any combination of up to six 100 Mbps channels, or one 300 Mbps channel plus five 100 Mbps channels. The TOSS will use the two active satellites and will have an option of four 100 Mbps channels, or one 300 Mbps channel plus three 100 Mbps channels. Requirements placed on the S/C by the TDRS characteristics will be considered below, using data from the TDRSS User's Guide as a basis (some parameter changes would be expected before the TDRSS design is frozen).

DOMSAT: The Domsat B is used as a typical communications link for the wideband data since overland links are limited at the TDRSS NASCOM interface to 1 to 2 Mbps; the Domsat can relay as many as 48 36 MHz channels, 24 each on C- and Ku-bands. For the purpose of this study, the data are assumed to be of the order of 75 MHz wide (subject to some adjustment and depending on the TDRSS specification for the 100 Mbps channels). The individual Domsat channels are up to 36 MHz wide, so typically the data would be reformatted from the 75+ MHz width to two

or three 36- MHz width channels. The data can be relayed either at C-band as is used in most currently established communications links, or may be at Ku-band where equivalent channels are to be established. The general capability of the Domsat indicate it is adequate to handle the TOSS data as outlined previously. The proposed configuration will cover the United States including Alaska and Hawaii. The procedure indicated by Figure 0-2 includes first a transmission of the data to a processing center where certain data may be extracted, processed, and stored. The processed data may be reformatted and retransmitted, probably through the same Domsat, to user ground stations distributed throughout the United States (and possibly elsewhere if required). The user receipt of the data completes the TOSS dissemination process.

Processing Center: Must include a Domsat ground terminal, but details otherwise are TBD. Crop and range grass data may be extracted from the Landsat information, and the resulting data recorded for further analysis. The processed (and probably compacted) data are formatted again as necessary, and transmitted to the several users, also requiring Domsat stations, for application of the data, including ground cover interpretation and map development.

Storage Terminal: A Domsat terminal at Sioux Falls, S. D., has been appointed as a storage facility for all data forwarded from the central processing facility. For high speed data, a wideband recorder is required (TDRSS also will have wideband recorders, although specifications have not been related to the Landsat specific requirements). Preferred recorders will have bandwidth capabilities in excess of 100 Mbps and can store each channel of S/C data separately for future reference.

## 0.2.2 OPERATIONAL DESCRIPTION

### 0.2.2.1 System Configuration

The general system considered was shown in Figures 0-1 and 0-2. The operational description will assume the Landsat S/C's are in orbit and are ready to begin a mapping task.

Initially, commands must be transmitted to the S/C's to set up their operational configurations and schedules, and establish the two-way data links. The method for accomplishing this is outlined in the TDRSS User's Guide (STDN No. 101.2) and is detailed therein. The Ku-band antennas on both the TDRS and the user S/C are very narrow beam, and must be tracking type antennas. (An S-band wider beam link is normally used for establishing the command link required to direct the two antennas.) Once the narrow band tracking loop is operating, the wideband data may be transmitted. The user S/C transponder is also required to include circuitry for range and range-rate tracking by the TDRSS tracking facility.

The user S/C may transmit data until the TDRS in use approaches the horizon, beyond which data either cease or the user S/C acquires the second TDRS and continues transmission.

The Ku-band data from the user S/C to the TDRS are translated to the downlink TDRSS frequency and sent to the ground station. Here it is processed as required to adapt to the Domsat format restrictions. The data may be demodulated at the TDRSS ground station or transferred as an IF signal to the Domsat ground station, at or near the location of the TDRSS ground station. The reformatting of data is TBD, but typically



may utilize a commutator which would place every third bit into a separate channel, thus reducing the data rate below the limit of each separate Domsat channel. The latter is currently limited to a 36 MHz bandwidth, and cannot accommodate the 100 Mbps data rates of the TM. Suitable synchronizing signals for recombining the channel data to reconfigure the original data are required; also a parity bit or error correcting code is required.

Data dissemination is predicated on a Domsat network permitting the data to be first transferred to a processing center at a TBD location; here certain data may be extracted and stored (crop and range grass data shown in Figure 0-2), and processed per user requirements. The data would be demodulated at the processing center, processed and remodulated with an appropriate format for transmission on to user locations. Included in Figure 0-2 is a recorder station which will record all data from the processing station. The data would normally have been placed in separate Domsat channels to isolate data for each destination.

The TDRSS normally utilizes the GSFC as a link to the central processing facility, which may be the GSFC facility itself if it can handle the data rates and volumes, and is dedicated for the use of the subject S/C's when required. A separate software center may be required for grouping the processed data properly for retransmission to users. GSFC is expected to use the Domsat link for all wideband data since the ground links will not have the necessary bandwidth.

Commands and controls to the user S/C's will also be implemented via the TDRSS links. The required forward data will be generated from inputs

of the several users and from the processing center inputs; formatted uplink data will follow the TDRSS methods, and the Landsat transponder design must also be adaptable to the TDRSS format.

#### 0.2.2.2 Orbit Considerations

The user S/C are assumed to be in a nominal 926 km altitude orbit (500 nm.), and will be in a polar orbit. If more than one user S/C is used simultaneously, they are assumed to be in identical orbits with equal spacings; that is, three user S/C would be in the same orbit but spaced  $120^{\circ}$  apart, and each would cover the same earth region with only the one-third of an orbit time delay. Figure 0-3 shows the configurations for one to four S/C; the TDRS's are in nearly equatorial orbits, and spaced  $130^{\circ}$  apart at approximately  $40^{\circ}$  and  $170^{\circ}$ W. (A spare TDRS is located between these two and is available in emergencies, but the coverage is restricted by its standby location until it is moved into position by its-orbital-propulsion system.)

The two TDRS vehicles are spaced less than  $180^{\circ}$  apart, and thus a gap in coverage is created on the far side of the earth as shown in Figure 0-4. This region is currently centered at  $75^{\circ}$ E (or  $285^{\circ}$ W) and will vary with user S/C altitude. Figure 0-5 shows the extent of the coverage gap for S/C altitudes of 1000, 926 (500 nmi.), 700, and 200 km. (The contours include a nominal correction for refraction based on TDRSS data; the peak is at a 1200 km altitude, above which there is no loss of contact between S/C and TDRS.) Figure 0-6 shows some typical orbit paths with the 926 km gap contour superimposed; the equatorial coordinates of the gap are about  $71.5^{\circ}$ E and  $78.5^{\circ}$ E, and the latitude extremes centered on

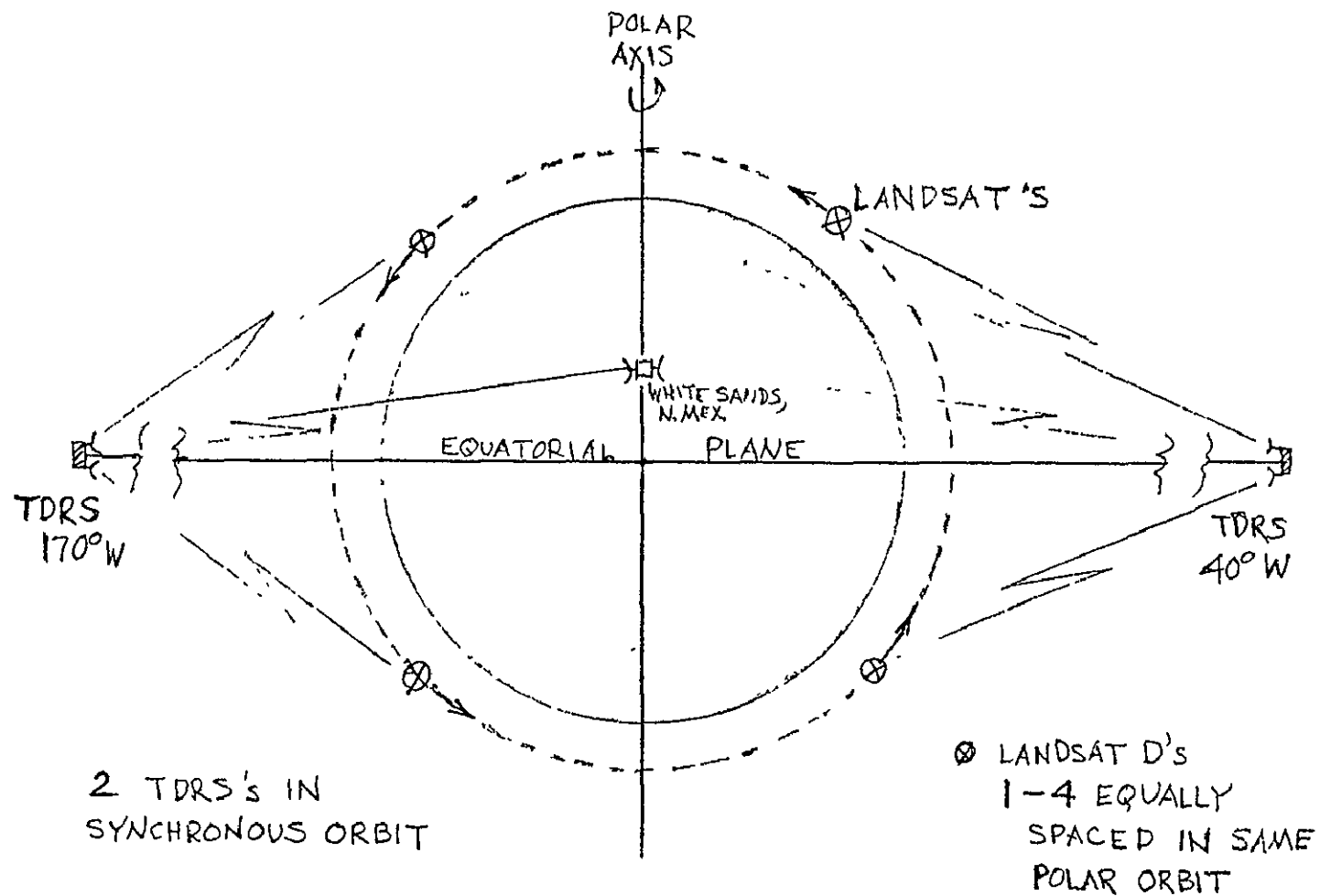


Figure 0-3 LANDSAT POLAR ORBIT - ONE TO FOUR S/C EQUALLY SPACED

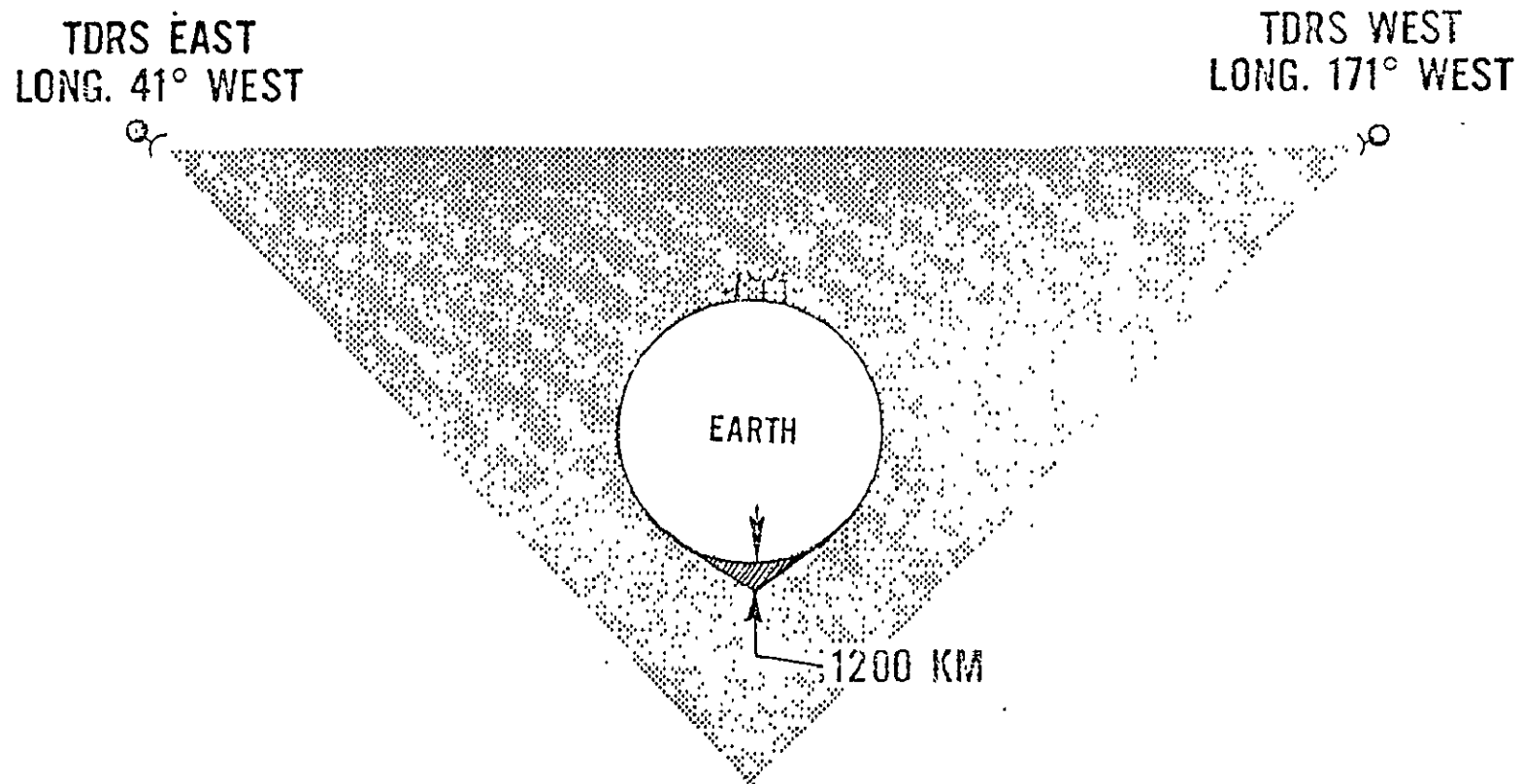


Figure 0-4 TRACKING AND DATA RELAY SATELLITE SYSTEM  
SHOWING COVERAGE GAP OF 1200 km. ALTITUDE

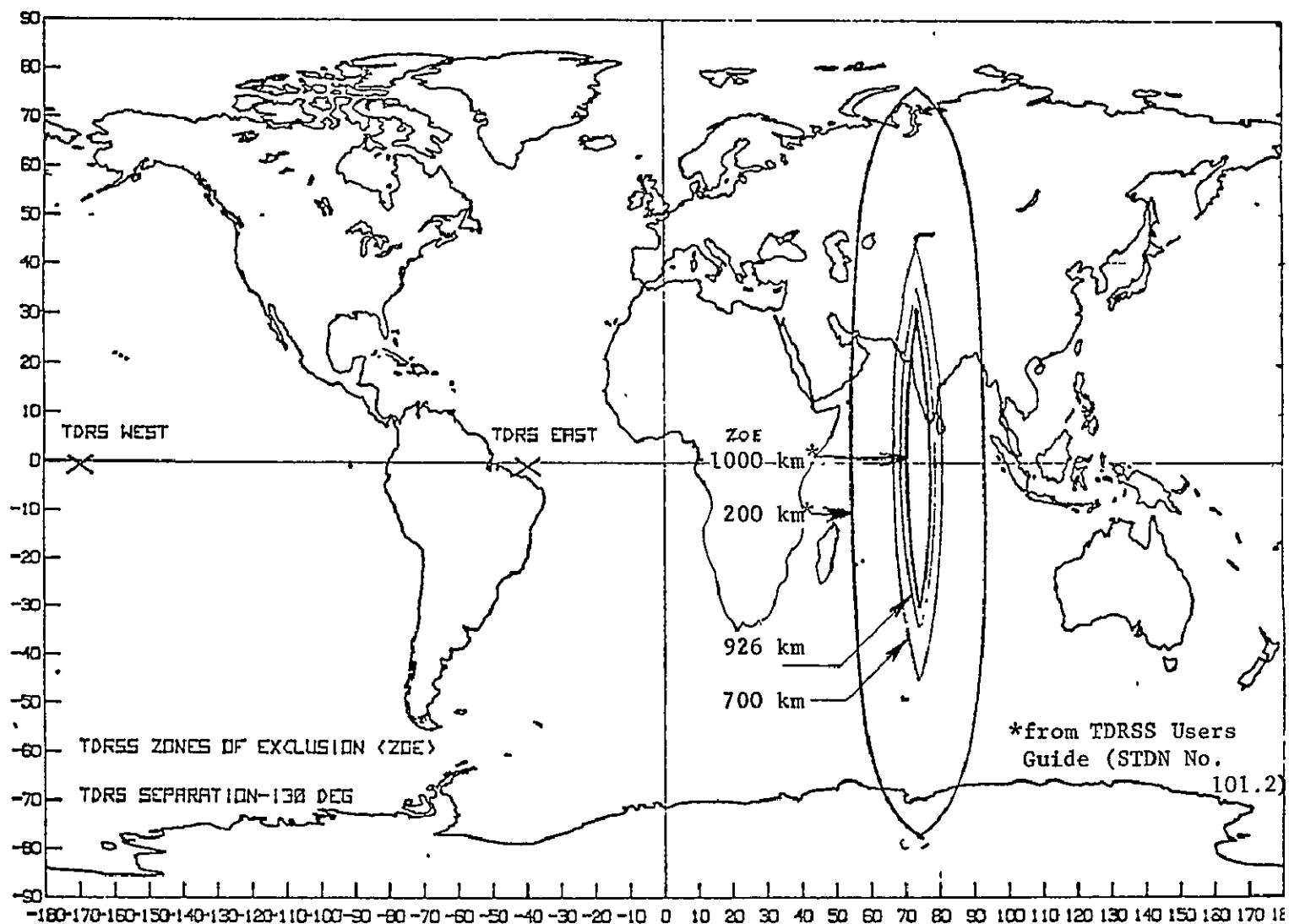


Figure 0-5 TDRSS ZONES OF EXCLUSION

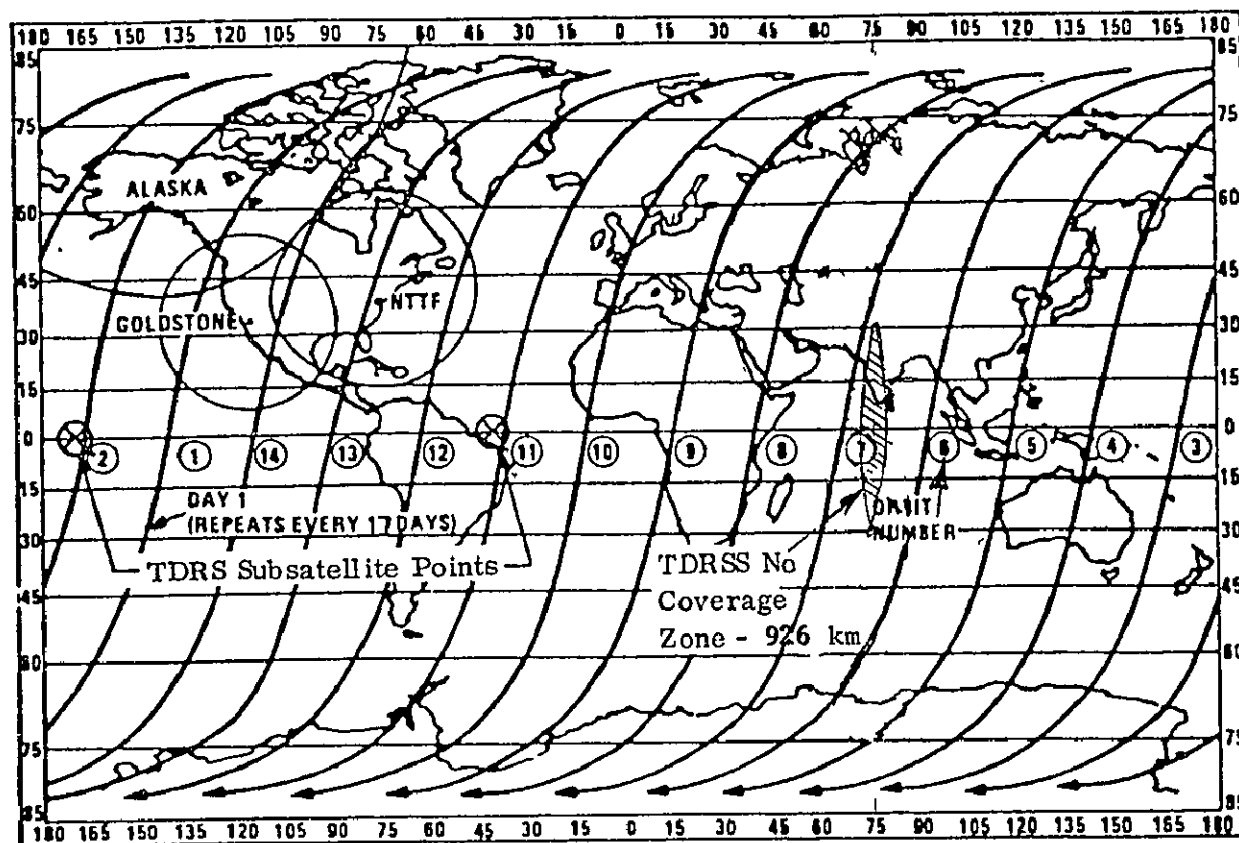


Figure O-6 TYPICAL USER S/C DAILY GROUND TRACE (DAYLIGHT  
PASSES ONLY)

75°E are  $\pm 30.8^\circ$ . Only when a user S/C orbit is a little east of the orbit #7 shown would the TDRS link continuity be broken; in all other cases, at least one of the TDRS's would be visible from a 926 km altitude.

#### 0.2.2.3 Sensors and Data

This study considers primarily the effects of using a Thematic Mapper (TM) as the sensor on a Landsat type vehicle; a Multispectral Scanner (MSS) is also included as a typical equipment for reduced performance or in a dual sensor S/C. The TM is a more advanced sensor with greater resolution. The nominal data rates considered for the two sensors are 100 Mbps for the TM and 15 Mbps for the MSS. If both are used simultaneously, the total data rate is the sum of the two; the bandwidth requirements would depend on how the data are formatted for transmission, but the probable approach is to isolate them on separate carriers or subcarriers. (In the General Electric EOS study, the two carriers were spaced 105 MHz.) If on-board recording is to be used, such as in the TDRSS coverage gap per Figure 0-4, the TM data may have to be compacted if the recorder cannot handle 100 Mbps; this was suggested in GE's EOS study where recorder limits were assumed to be 15 Mbps.

Data stream formatting for transmission to the ground will be in accordance with TDRSS specifications. The TDRSS data rate restrictions place corresponding limits on the S/C sensors that can be used simultaneously. The TM is assumed to require 100 Mbps although it could be operated in a slightly degraded mode if data rate reduction had a priority over the high resolution capabilities. The MSS is assumed to

have a data rate of 15 Mbps. The combinations of sensors and number of Landsat vehicles operating simultaneously with the TDRSS are listed in Table 0-1. For the data rates of the sensors and the TDRSS rate restrictions, the Landsat S/C would normally be limited to one TM operating at any one time; with only one or two Landsats, an additional TM could be included in a S/C (if operational requirements made this advantageous) or one or more MSS's could be used with the TM to provide additional data. In any case, the entire system is restricted to either four 100 Mbps channels, or a combination of three 100 Mbps plus one 300 Mbps channels.

#### 0.2.2.4 Data Handling and Dissemination

The data generated in the user S/C are formatted into suitable data words with identifying addresses and codes. The TDRSS requires that the data be QPSK modulated onto a carrier of 15.0085 GHz. For data at 100 Mbps or less, the data use SQPSK (staggered QPSK) with alternate bits on the I and Q channels and displaced by 1/2 bit in time. For data totaling up to 300 Mbps, the data streams will be made up of two or more independent signals, in which case one set of data is on the I channel and the other on the Q channel. In addition to this modulation, the transponder is required to receive the initial acquisition data (frequency-hop (FH) and pseudorandom noise (PN) coding) and to return to PN coded signal prior to transmitting data. These times also involve angle tracking acquisition with the Ku-band monopulse antennas at each end of the link. These data rates are all relatively low; higher data rates are used after the data link is established and confirmed.



TABLE 0-1

## CHANNEL CAPACITY UTILIZATION OF TDRSS VERSUS S/C SENSORS

<u>TDRS's</u>	<u>LANDSAT B's</u>	<u>SENSORS</u>	<u>TDRS #1 CHANNELS</u>	<u>TDRS #2 CHANNELS</u>
1	1	1 TM 2 TM MSS, 1 or 2 1 TM + MSS's 2 TM + MSS's	1 - 100 Mbps 2 - 100 or 1 - 300 Mbps 1 - 100 2 - 100 or 1 - 300 1 - 300	{ same, used on other half of orbit
2	2	1 TM each 2 TM each MSS, 1 or 2 1 TM + MSS's { 2 TM + MSS (one S/C) 2 TM (other S/C)	1 - 100 Mbps 2 - 100 or 1 - 300 Mbps* 1 - 100 2 - 100 or 1 - 300* { 1 - 300	
2	3	1 TM each 1 TM + MSS's each MSS, 1 or 2 each	2 - 100 Mbps Not possible within data rate assumptions and TDRSS 2 - 100	1 - 100 Mbps 2 - 100 1 - 100 Restrictions
2	4	1 TM each MSS, 1 or 2 each	2 - 100 Mbps 2 - 100	2 - 100 Mbps 2 - 100

\*Only one TDRS at a time can utilize the 300 Mbps channel; if used, the TDRS's must also switch modes as the S/C switch from one to the other as they traverse their orbit.

Upon receipt of the user S/C's signal stream, the data are shifted in frequency in the TDRS transponder to the appropriate downlink frequency and transmitted to the TDRSS ground station. Here it is either converted to an IF for direct transmission through the NASCOM interface, or is demodulated and sent through a bit synchronizer and Viterbi Decoder before transmission through the NASCOM interface. Up to this point, the TDRSS may have up to four parallel real-time data channels; these are sent to a nearby Domsat terminal where the bits are formatted for adaptation to the spectrum restrictions of the Domsat links. The Domsat channels are 36 MHz wide, each.

The Domsat is used for all subsequent data transmission, which may be to GSFC or other location for processing; it must be reformatted into original form before such processing. The data are then utilized in extracting detailed information for the various users. It is formatted in a manner suitable for retransmission over the Domsat link; presumably the processing would reduce the redundant or irrelevant data such that the 36 MHz bandwidths of the Domsat channels would be entirely adequate. The "real-time" feature will incorporate the processing time delay, which is normally quite short and tolerable in view of the processing equipment utilization costs and potential complexities for a system not using the central processor.

Alternate system suggestions include a cost analysis of the locations of the various elements of the data handling system on the ground to minimize the number of links tied up (i.e., cost of system operation) and the number of separate processing or storage facilities. There is

also a possibility of transmission of data at a slower rate (with parallel channels for near real-time), particularly if the computer processor is limited in operating rate and cannot process all the data in real time. Limited users, interested only in small regions or lower quality data, might well profit by recording the data at the TDRSS and transmitting the data at a much slower rate, but at a rate still adequate to permit complete data analysis prior to the time that any subsequent action relative to TOSS would be initiated. This raises the basic question of what definition to use for "real-time," and what is the cost of small delays where the sensors are not used with a 100% duty cycle anyway.

### 0.3 DESCRIPTION OF SYSTEM COMPONENTS

#### 0.3.1 LANDSAT EQUIPMENT - TRANSPONDER

The S/C transponder is required to include all features demanded by the TDRSS as well as the ability to handle the data rates of the sensors on board. Thus in formulating a transponder configuration, the elements indicated by the TDRSS program are first incorporated, and then the appropriate modulation circuitry is added. A block diagram of a typical transponder is shown in Figure O-7. The diagram includes some detail in the requirements imposed by the TDRSS, including the tracking loops, PN decoding, command data output, and frequency synthesizer. The sensor data to be returned to the ground are at the bottom of the figure. Not included in the diagram are the S-band link components required for acquisition and the Ku-band beacon also required for the Ku-band tracker acquisition process.

Figure 0-7. KU-BAND SINGLE-ACCESS USER TRANSPONDER FOR LANDSAT S/C

The "Data Message Generator" formats the sensor output data, adding identification and address to each separate data group to be transmitted. A block diagram showing a possible data handling arrangement in the S/C transponder is shown in Figure 0-8; this includes a data compactor which may be acceptable for certain users and may be necessary for the rare cases when the S/C is in the dead region of TDRS coverage (Figure 0-4) and any data output from the sensors may be stored and dumped later. Figure 0-8 is a modification of the EOS transponder circuit. The EOS placed the MSS data on a subcarrier with PCM/FM modulation which is not acceptable in the TDRSS system; QPSK is used here.

The Ku-band user transmitter specified by the TDRSS link requirements is sufficient to determine the transmitter size for present considerations. The link parameters are listed in Section 0.5, and indicate an EIRP of 57.4 dBw, which can be effected by a 3.8 meter (12.5 foot) antenna and an 11.2 watt transmitter (100 Mbps data).

The study showed typically the 11.2 watt output which can be used directly in the S/C here; the 200+ Mbps data rate would require about double the lower data rate power. The antenna suggested is identical with the Ku-band antenna of the TDRSS.

#### 0.3.2 TDRS TRANSPONDER

The TDRS transponder, as defined, includes both an S-band and a Ku-band capability. The Ku-band channel is centered on 15.0085 GHz. The transponder includes two antenna/receiver units, each arranged to receive either a 100 Mbps channel in which case the transmission spectrum to the ground station can accommodate two channels of data, or one 300

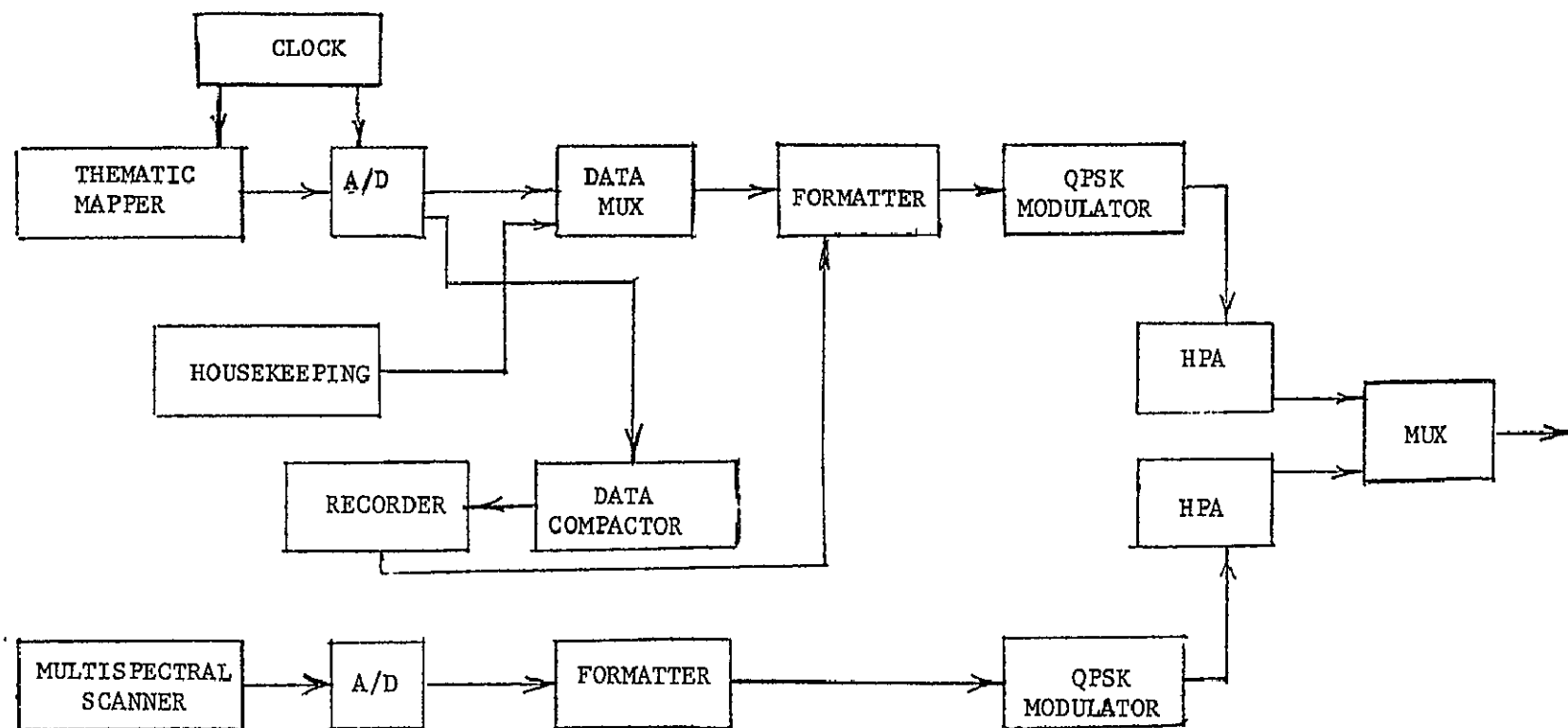


Figure 0-8. GENERAL ARRANGEMENT FOR DATA TRANSMISSION OF  
SENSOR DATA FOR LANDSAT TO TDRS

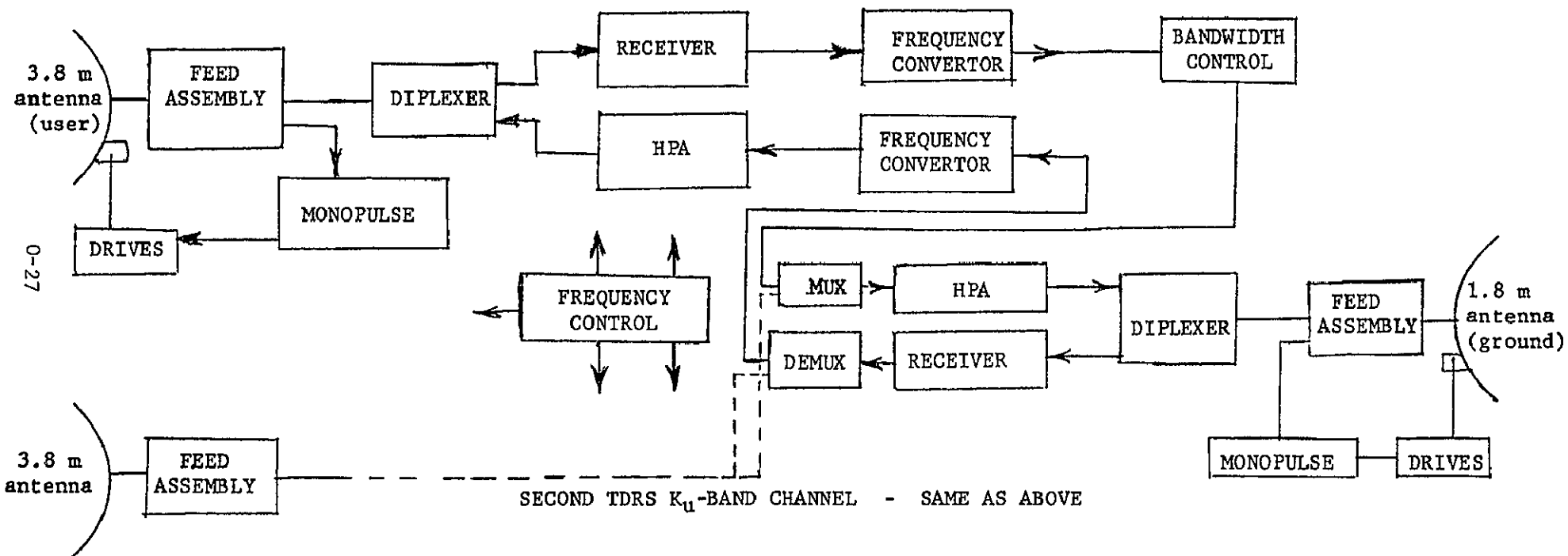
Mbps channel which restricts data to only one of the TDRS's two antenna/receiver channels. A simplified diagram of the TDRS transponder is shown in Figure O-9. The receiver section uses an uncooled paramp which results in a system noise temperature of about 560°K; the overall G/T is about 25 dB/°K.

The data stream is only translated in frequency by the TDRS. The transponder also includes the angle tracking acquisition loops, although the range and range-rate tracking is accomplished at the ground station equipment.

### 0.3.3 TDRSS GROUND STATION

The TDRSS ground station has been configured to provide adequate performance for data of the type generated by the Landsat type S/C. The antenna is nominally 18.3 meters in diameter, and the LNA is an uncooled paramp; the overall G/T is about 40 dB/°K. The data stream received is processed by either a direct transfer of the IF signal to an output terminal, or by demodulation with bit reforming in the bit synchronizer and error correction in the convolution decoder. The former is adequate if the S/N is high throughout the system; the latter would be preferred where the noise contributions from the subsequent Domsat and data processing system would not be acceptable.

The data output, of either format, will be sent to a NASCOM interface which will arrange for channeling the signal to the proper destination. The handling of wideband data over about 1 Mbps has not been well defined, but will use a Domsat type facility. This facility may be a Ku-band CML type, equivalent to the proposed Domsat B configuration



(S-Band components omitted)

Figure 0-9. PARTIAL BLOCK DIAGRAM OF TDRS TRANSPONDER  
 $K_u$  -BAND LINK



(which has 24 channels on each of C-band and Ku-band). These channels require some alterations to the data which has a wider band than any one of the Domsat channels. This process is assumed to be a Domsat station responsibility, although the NASCOM interface will perform the operation. The TDRSS ground station includes recorders at the NASCOM interface which could be used for the S/C data if the recorder bandwidths are sufficient. Otherwise, the Landsat program will provide only data recorders at pre-selected ground terminals noted in Figure 0-2. The Domsat B may also be configured with a wider band channel which would result in no reformatting of data for Domsat transmission.

Control of the Landsat type S/C will be through the standard TDRSS uplink, with commands generated by the Landsat control center and transmitted via GSFC and NASCOM interfaces to the TDRSS ground station. Data are required to have the proper format before reaching the ground station; here it is scheduled, the acquisition and ranging codes added, and the data transmitted over a conventional forward-link channel. There is a restriction on uplink data rate, indicated in Section 0.5, Link Calculation, but it is not a problem with a 3.81 meter (12.5 foot) antenna on the Landsat S/C.

#### 0.3.4 DOMSAT B EQUIPMENT

The Domsat B type of communications link will be sized to accommodate all users expected in the 1980-1990+ time frame. The channel widths of 36 MHz are expected to be retained, and the 100 or greater Mbps data will have to be reformatted to adapt. (However, a double or triple width channel could be incorporated before a design freeze.) The

data would either be divided by splitting the spectrum into n parts (typically 2 or 3) and reconstructing the spectrum at the receiving end, or the data would be divided into two or three groups at the video rather than IF level and each group modulated through a separate Domsat channel.

The complete Domsat configuration has not been defined, but the links now used for Intelsat and the CML transponder may be used. The Domsat transmitter has been sized initially at 7 watts output for the C-band channels and 20 watts for the Ku-band channels. Ground station antenna, transmitter, and receivers will be sized accordingly; the decision on dividing the operational requirements to obtain optimum system parameters for each location is TBD.

#### 0.3.5 USER EQUIPMENT

The data supplied by NASA to the user processing center will usually be - - a QPSK signal; the center provides the demodulator (probably), bit synchronizer, any additional error correction, recorders as required, and map generating facilities. The Central Processor (Figure 0-2) will route the data to the specific users, routing as required when more than one user S/C is transmitting data simultaneously. The equipment to be located at each Domsat terminal is TBD, but generally will include demodulator chains, recorders, computers, displays and monitoring facilities.

#### 0.4 SYSTEM ALTERNATIVES: DATA STORAGE FOR DELAYED PROCESSING

The basic TOSS assumes real time data delivery to the users from the S/C. However, circumstances may dictate a delay in data due to NASA schedules of the overall system with other users. Some specific circumstances which could use data storage include:

On-board. When the user S/C is not in view of at least one of the TDRS's per Figure 0-6; when a TDRS channel is temporarily not available due to competing users; when the user can use less data and the channel is tied up otherwise such as MSS data when the TM is utilizing the entire channel at a given time.

TDRSS Ground Station. When the NASCOM interface is temporarily inactive; when the required Domsat channels are temporarily unavailable.

Domsat Ground Station. When only a part of the data is to be extracted without destruction of any of the data for other destination; when Domsat channels to user ground stations are temporarily unavailable.

From a cost aspect, most of the interim data storage facilities are only insurance devices to prevent the loss of data by eliminating a strict requirement that the entire system be real-time in action in all instances. The probability of down time and the cost of re-acquiring a given set of data would determine the value of having interim storage; the cost of the storage must be less than this value to justify the additional storage. Such a study would be extensive in that it must include projected usage of the various links involved in the overall TOSS (TDRSS, NASCOM, Domsat, processing computer) and would constitute an element of a detailed system study.

Current recorders are capable of handling about 15 Mbps by splitting the channel spectrum; alleged future recorders should be capable of handling up to 100 Mbps but the availability date for a flight model has not been projected.

#### 0.5 OPERATIONAL CAPABILITIES - LINK CALCULATIONS

A basic concern of a system like TOSS is the parametric design of the subject subsystem to integrate into the overall system, considering subsystems already determined in other programs. The Landsat type S/C transponder is a variable item for the system and integrates with the TDRSS, Domsat and lesser programs such as wideband recorder development. The basic requirements for the user S/C transponder can be extracted from the link analyses which are indicated in Table 0-2. (The data is largely from the TDRSS User's Guide; the S/C transmission and reception requirements are typical for the overall system requirements.) The Domsat requirements for link calculations cannot be influenced by the S/C data, except there may be some future options on type of modulation to be used. In general, the Domsat will be sized to serve the users' anticipated requirements, and problems with the S/C data will be resolved when problems are identified.

Table 0-2 includes different parameters to show effects. From the TDRS to the user S/C, the data rate is restricted by the fixed EIRP of the TDRS forward link, and the only variable is the user S/C receiver antenna gain and receiver noise temperature, or G/T. Two different receiving antennas and complementary preamplifiers are shown, either combination resulting in a data rate limit for outgoing commands of

TABLE 0-2

TOSS LINK PARAMETERS VIA TDRSS

Parameter	Ground to TDRS	TDRS to User (Typical)		User to TDRS (Typical)		TDRS to Ground
f (GHz)	15.20	13.775	13.755	15.0085	15.0085	13.937
EIRP dBW at ant.	87.8	49.0	49.0	57.4	60.4	56.7
P <sub>t</sub> Watts (HPA)	148	0.79	0.79	11.2	22.3	12.6
Ant. Gain (Xmt)	66.1	52	52	52.6	52.6	45.7
Ant. Diam (Xmt) (meters)	18.3	3.8	3.8	3.8	3.8	1.83
DATA RATE - dB	74 to 77	49.9 + G/T		80	83	80
- Mbps	25 to 50	3.8	3.0	100	200	100
C/N (E <sub>b</sub> /N <sub>0</sub> ) dB	9.9	9.9	9.9	9.6	9.6	9.9
Margins dB	29.5	4.0	4.0	3.0	3.0	11.4
Ant. Gain (Rcv)	46.5	51.9	41.1	52.6	52.6	66.1
Ant. Diam (Rcv) (meters)	1.83	3.8	1.06	3.8	3.8	18.3
T °K	4266°	3966°	416°	710°	710°	350°
G/T dB/°K	9.8	15.9	14.9	24.1	24.1	40.7

about 3 to 4 Mbps. A reasonable upper limit using the larger antenna (3.8 meters) and the uncooled paramp ( $416^{\circ}$ ) could increase the data rate to as much as 36 Mbps for the command link; this probably won't be necessary.

On the return path, two data rates are shown for the "User to TDRS"; 100 and 200 Mbps. The difference shows up as 3 dB more power for the wider band case. In neither case is the transmitter power excessive with the 3.8 meter antenna, 11.2 or 22.3 watts for the two cases.

Additional parameter variations can be evaluated simply by altering one or more variables and noting effects. The losses incurred in the circuitry, modulation losses, space and weather losses, and operating losses are not shown but were included in the total analysis, using numbers from either the TDRSS or EOS documentation.

#### 0.6 COST FACTORS

Cost estimates for the TOSS operation are subject to unknown factors inasmuch as the entire system is dependent on TDRSS and Comsat B costs, neither of which are determined. However, some general aspects can be considered qualitatively to compare alternatives:

- o The cost of TDRSS use is essentially independent of data rate if Ku-band is required. The narrow beam Ku channel can be directed at only one user, and that user will pay the price for the complete channel. When data rates exceed 100 Mbps, the user may require two Ku channels in the TDRSS, and the cost will double. However, the cost for either a TM or one or more MSS's using a single Ku channel should be the same.

- o The cost of the Domsat type data link will depend on bandwidth or data rate, but only up to a point. The Domsat will charge in proportion to bandwidth required, but the bandwidth will be contracted for in advance, and probably will be charged to the Landsat data user whether used or not. Programs other than TOSS may require the wider bandwidths, or the Landsat may require the wider band for some S/C's but a narrower band for others using only an MSS. If the bandwidth is contracted for ahead of actual usage, and the requirements include wide band use for one or more users, then cost is again independent of data rate, and the TM would operate at the same cost as the MSS.
- o However, the MSS uses only 15% of the TM bandwidth. At \$1M per year per Domsat channel, the TM might cost \$2M (2 channels for 100 Mbps) for one year of operation for a single S/C (or up to \$8M for four S/C using TM's); the MSS channel costs would run about \$150K per sensor, or \$1.2M for four S/C with one MSS each. The value of the added TM data must be assessed to determine whether it warrants the added \$6.8M.

#### 0.7 EXTENT OF TDRS BLIND REGION

The TDRSS blind area for a S/C at 926 km altitude was shown in Figures 0-3 through 0-5. The equations to determine these regions are geometrically straightforward. For a quick check on the extent of the blind region, the equations below are included for obtaining the longitude width at the equator and the latitude maximums. Neglecting refraction for the first case:

$$\text{Delta longitude} = 2\phi \quad (\text{total width})$$

$$\phi = \theta - 56.32^\circ$$

$$\theta = \sin^{-1}(6370/6370 + h)$$

Where h is altitude in km.

$$\text{Latitude max.} = \cos^{-1}((81.32^\circ) - \theta / 25^\circ)$$

These numbers are only for TDRS locations spaced  $130^\circ$  apart and in the equatorial plane.

For a more realistic set of numbers, refraction may be included. In the case of TDRSS, the altitude above which there is no blind area was indicated to be 1200 km, while the no-refraction calculation indicates 1285 km. The difference, if due entirely to refraction in the atmosphere, represents about a  $.95^\circ$  bending. Then the above equations can be shown to be:

$$\text{Delta longitude} = 2 (\theta - 57.27^\circ)$$

$$\theta = \sin^{-1}((6370/(6370 + h)) \cdot \sin 89.05^\circ)$$

$$\text{Latitude Max.} = \cos^{-1} ((82.27^\circ - \theta) / 25^\circ)$$



**APPENDIX P**  
**ERROR ANALYSIS**

# APPENDIX P

## ERROR ANALYSIS

### P.1 INTRODUCTION

In this appendix expressions will be derived for four of the five sources of error in the TOSS Missions. The five error sources are:

- Area Mensuration
- Classification Errors
- Classification Bias
- Small Fields Cutoff Bias
- Sampling

The fifth source (sampling) is discussed separately in Appendix M. It will be shown that the mensuration and classification errors diminish by  $1/\sqrt{N}$  where N is the number of fields measured. Effectively then the contribution to the total error from these two sources will go to zero as N gets large. The bias errors, classification and sensor cutoff errors, are however significant contributions to the total crop error.

Assume that the uncertainties in the estimation of the field size have been obtained. Let the estimated field size be denoted by  $\hat{A}$ , and the mean and variance of this estimator be given not directly but in terms of the relative error i.e.

$$\hat{\psi} = \frac{\hat{A}}{A} \quad (1)$$

Where A is the true value of the size of the field and  $\hat{\psi}$  is the indicated ratio. Furthermore, let the moments of  $\hat{\psi}$  be denoted by

$$E(\hat{\psi}) = \bar{\psi} \quad \text{Var}(\hat{\psi}) = \sigma_{\psi}^2 \quad (2)$$

One should note that the moments of the area estimate can be expressed as:

$$E(\hat{A}) = A E(\hat{\psi}) \quad \text{VAR}(\hat{A}) = A^2 \sigma_{\psi}^2 \quad (3)$$

Let the total crop size in acres estimated in a particular mission be given by  $\hat{A}_T$  then this quantity can be written as the sum of the individual field sizes, determined by the classifier to consist of the same substance  $\alpha$ . Let  $\hat{A}_i$  be the  $i$ th field size estimate of the crop being estimated and  $\hat{B}_i$  be the  $i$ th field size estimate classified incorrectly as  $\alpha$ . Then

$$\hat{A}_T = \sum_{i=1}^N \hat{A}_i + \sum_{i=1}^M \hat{B}_i \quad (4)$$

where  $N, M$  are obviously the number of fields of  $\alpha$  and not  $\alpha$  respectively.

Note that  $N, M$  are random variables and will be treated as such in the subsequent analysis. In deriving expressions for the moments of  $\hat{A}_T$ , some results on conditional expectations will be needed. From Parzen (P. 55).

$$\begin{aligned} E(\hat{A}_T) &= E(E(\hat{A}_T/M, N)) \\ \text{VAR}(\hat{A}_T) &= \text{VAR}(E(\hat{A}_T/M, N)) + E(\text{VAR}(\hat{A}_T/M, N)) \end{aligned} \quad (5)$$

First, consider the conditional expectation

$$E(\hat{A}_T/M, N) = \sum_{i=1}^N E(\hat{A}_i) + \sum_{i=1}^M E(\hat{B}_i) \quad (6)$$

$$= \bar{\psi} \sum_{i=1}^N A_i + \bar{\psi} \sum_{i=1}^M B_i \quad (7)$$

The assumption was made that  $\bar{\psi}$  is independent of field size. Therefore,

$$E(\hat{A}_T/M, N) = \bar{\psi} [N \bar{A} + M \bar{B}] \quad (8)$$

and finally

$$E(\hat{A}_T) = \bar{\psi} [\bar{N} \bar{A} + \bar{M} \bar{B}] \quad (9)$$

where  $\bar{N}, \bar{M}$  are the expected values of  $M, N$  respectively and can be obtained from the performance measures of the classifier.

Furthermore, if the average field size does not depend on the type of crop then

$$E(\hat{A}_T) = N_T \bar{A} \bar{\psi} \quad (10)$$

and since the true value of the area of the crop is given by  $A_T = N_T \bar{A}$  (11)

then the mean value of the relative error is:

$$\bar{\psi}_T = E \left( \frac{\hat{A}_T}{A_T} \right) = \bar{\psi} \quad (12)$$

which says that the quantity  $\bar{\psi}$  is preserved under the summing operation. If

the estimator  $\psi$  is unbiased then  $\bar{\psi} = 1$  and the expected value of the field size is its true value. However, if there is a bias in the measurement system,  $\bar{\psi} \neq 1$

and EQ (10) or (12) can be used to estimate the propagated error in the total

crop. The percent error is obviously given by  $1 - \bar{\psi}_T = 1 - \bar{\psi}$  (13)

## P.2 THE VARIANCE

The variance estimate of  $\hat{A}_T$  consists of two terms, first the variance of the conditional expectation, from (6)

$$\text{VAR}(E(\hat{A}_T/M, N)) = \text{VAR} \left[ \sum_{i=1}^N E(\hat{A}_i) + \sum_{i=1}^M E(\hat{B}_i) \right] \quad (14)$$

$$= \bar{\psi}^2 \left[ \text{VAR} \sum_{i=1}^N A_i + \text{VAR} \sum_{i=1}^M B_i \right] \quad (15)$$

Let the field sizes  $A_i$  and  $B_i$  be written as

$$A_i = \bar{A} + \Delta_{Ai} \quad B_i = \bar{B} + \Delta_{Bi} \quad (16)$$

then (15) becomes

$$\begin{aligned} \text{VAR}(E(\hat{A}_T/M, N)) &= \bar{\psi}^2 (\text{VAR}(\bar{N}\bar{A}) + \text{VAR}(\bar{M}\bar{B})) \\ &\quad + \text{VAR} \left( \sum_{i=1}^N \Delta_{Ai} + \sum_{i=1}^M \Delta_{Bi} \right) \\ &= \bar{\psi}^2 \left[ (\bar{A}^2 \sigma_N^2 + \bar{B}^2 \sigma_M^2) + (\bar{N} \sigma_A^2 + \bar{M} \sigma_B^2) \right] \end{aligned} \quad (17)$$

For the unconditional variance, the term

$E(\text{Var}(\hat{A}_T/N, M))$  is needed

$$\begin{aligned} E(\text{Var}(\hat{A}_T/M, N)) &= \text{Var}\left(\sum_{i=1}^N \hat{A}_i + \sum_{i=1}^M \hat{B}_i\right) \\ &= \sum_{i=1}^N \text{Var}(\psi_i A_i) + \sum_{i=1}^M \text{Var}(\psi_i B_i) \\ &= \sigma_\psi^2 \left( \sum_{i=1}^N A_i^2 + \sum_{i=1}^M B_i^2 \right) \end{aligned} \quad (18)$$

But the sum of the squares may be written

$$\begin{aligned} \sum_{i=1}^N A_i^2 &= \sum_{i=1}^N (\bar{A} + \Delta_{Ai})^2 = \sum_{i=1}^N (\bar{A}^2 + 2\bar{A}\Delta_{Ai} + \Delta_{Ai}^2) \\ &= N\bar{A}^2 + 2\bar{A} \sum_{i=1}^N \Delta_{Ai} + \sum_{i=1}^N \Delta_{Ai}^2 \end{aligned}$$

Taking expected values, with  $E(\Delta_{Ai}) = 0$

$$E(\text{Var}(\hat{A}_T/M, N)) = \sigma_\psi^2 \left[ \overline{NA}^2 + \overline{MB}^2 + E\left(\sum_{i=1}^N \Delta_{Ai}^2 + \sum_{i=1}^M \Delta_{Bi}^2\right) \right] \quad (19)$$

The unconditional variance is then written as the sum of EQ(17) and EQ(19).

$$\begin{aligned} \sigma_{\hat{A}_T}^2 &= \bar{\psi}^2 \left[ (\bar{A}^2 \sigma_N^2 + \bar{B}^2 \sigma_M^2) + (\bar{N} \sigma_A^2 + \bar{M} \sigma_B^2) \right] \\ &+ \sigma_\psi^2 \left[ \bar{N} \bar{A}^2 + \bar{M} \bar{B}^2 + E\left(\sum_{i=1}^N \Delta_{Ai}^2 + \sum_{i=1}^M \Delta_{Bi}^2\right) \right] \end{aligned} \quad (20)$$

The relative variance  $\text{Var}(\hat{A}_T/A_T)$  is obtained by dividing both sides by  $A_T^2$ .

Furthermore, one can assume that the field statistics are homogeneous.

i.e.  $\bar{A} = \bar{B}$ ,  $\sigma_A^2 = \sigma_B^2$  if  $\psi_T = \hat{A}_T/A_T$  then

$$\begin{aligned} \sigma_{\psi_T}^2 &= \bar{\psi}^2 \bar{A}^2 (\sigma_N^2 + \sigma_M^2) + \sigma_\psi^2 \frac{\bar{A}^2 N_T}{N_T^2 \bar{A}^2} \\ &+ \theta(1/A_T^2) \end{aligned} \quad (21)$$

### P.3 A CHARACTERIZATION OF THE CLASSIFIER

Let  $N_1$  be the number of fields of a particular crop  $\alpha$  being measured, and  $N_2$  be the number of fields not containing  $\alpha$  then  $N_T = N_1 + N_2$  is the total number of fields in the given mission. The classifier can be depicted (as in the figure below) as a box with outputs  $p_c N_1$  and  $p_c^- N_2$ , the fractions  $p_c$  and  $p_c^-$  are respectively the probability that a field containing  $\alpha$  is classified as  $\alpha$  while  $p_c^-$  is the probability that a field not consisting of  $\alpha$  is classified as  $\alpha$ .



The number of fields then classified as  $\alpha$  can be written as  $N_c$  and the expected value of  $N_c$  is given by

$$E(N_c) = p_c N_1 + p_c^- N_2 \quad (22)$$

The variance of  $N_c$  can be obtained by assuming that the random quantities  $p_c N_1$ , and  $p_c^- N_2$  are binominally distributed.

$$\text{Var}(N_c) = N_1 p_c (1 - p_c) + N_2 p_c^- (1 - p_c^-) \quad (23)$$

These quantities can be used to simplify the expression for the total variance in EQ(21). In that expression  $\bar{N} = p_c N_1$  and  $\bar{M} = p_c^- N_2$ , therefore,

$$\sigma_N^2 = p_c (1 - p_c) N_1 \quad \sigma_M^2 = p_c^- (1 - p_c^-) (N_T - N_1) \quad (24)$$

where  $N_T$  is the total number of fields in a mission. Furthermore, assuming that the field statistic themselves are homogeneous in the sense that  $\bar{A} = \bar{B}$  then

$$\sigma_{\psi_T}^2 = \frac{\sigma_N^2}{N_T} + \bar{\psi}^2 \bar{A}^2 \left[ \frac{N_1 p_c (1 - p_c) + (N_T - N_1) p_c^- (1 - p_c^-)}{(N_T \bar{A})^2} \right] + \theta \frac{1}{A_T^2} \quad (25)$$

The final term is of the order  $1/A_T^2$  and has been determined to be negligible.

Then

$$\sigma_{\Psi_T}^2 = \frac{\sigma_{\Psi}^2}{N_T} + \frac{\bar{\Psi}^2}{N_T} \left[ \left( \frac{N_1}{N_T} \right) p_c (1 - p_c) + \left( \frac{N_T - N_1}{N_T} \right) p_c^- (1 - p_c^-) \right] \quad (26)$$

The a-priori probabilities  $N_1/N_T$  and  $(N_T - N_1)/N_T$  can be estimated from existing crop statistics.

#### P.4 CLASSIFIER BIAS

It should be noted that both terms in the total variance have a  $1/N_T$  factor, this indicates that as the number of measurements become large, the error contribution will become small. What should be further noted is that the expected value of  $N_c$ , the number of fields determined to be of the same crop, is not equal to  $N_1$ , the true number of fields of the particular crop under investigation because of the existence of both omission and commission errors, i.e.

$$E(N_c) = p_c N_1 + p_c^- N_2$$

where the notation has been changed so that

$p_c$  classifier probability of detection declaring  $\mathcal{O}$  when  $\mathcal{O}$  occurs

$p_c^-$  classifier false alarm rate declaring  $\mathcal{O}$  when  $\mathcal{O}$  does not occur (commission error).

$p$  a priori density of  $\mathcal{O}$

Then

$$E \left( \frac{N_c}{N_T} \right) = \hat{p} = p_c p + p_c^- (1 - p) \quad (27)$$

where  $\hat{p}$  is the estimated density of crop  $\mathcal{O}$ . In terms of areas then the measured acreage of  $\mathcal{O}$  say  $\hat{A}_M$  is given by

$$\hat{A}_M = \hat{p} A_T \quad (28)$$

Now suppose the density of  $\Omega$  as measured as a result of the classifier output is biased, that is, it is determined that the density  $\hat{p}$  is always consistently in error. If this can be determined by existing statistics or by setting up a special procedure to measure the density in some given regions, then the measured area may be corrected (the bias removed) as

$$\hat{A}'_M + \hat{A}_M \frac{p}{\hat{p}} = pA_T \quad (29)$$

where  $p$  is the newly determined value of the density. If this measurement of area  $\hat{A}'_M$  is unbiased, the variance of the measurement can be obtained as follows:

$$\begin{aligned} \frac{\text{Var}(\hat{A}'_M)}{A_T^2} &= \frac{\text{Var}(\hat{A}_M \frac{p}{\hat{p}})}{A_T^2} \\ &= \frac{\hat{A}_M^2}{A_T^2} \text{Var}\left(\frac{p}{\hat{p}}\right) \\ &= \frac{\hat{p}^2}{p} \text{Var}\left(\frac{p}{\hat{p}}\right) \end{aligned} \quad (30) \quad (31)$$

So it remains to compute the variance of the ratio  $p/\hat{p}$ , where the variance of  $p$  is assumed to be known or at least can be estimated as a function of the method of determining this value. Let this value be denoted by  $\sigma_p^2$ .

Under suitable conditions, the variance of any function  $f(x)$  may be given in terms of the variance of  $x$  and the function evaluated at the mean of  $x$ .

Papoulis i.e.

$$\text{Var}(f(x)) = \left( \frac{df}{dx} \bigg|_{x=\mu} \right)^2 \sigma_x^2 \quad (32)$$

Therefore,

$$\begin{aligned} \text{Var}\left(\frac{p}{\hat{p}}\right) &= \left\{ \frac{d}{dp} \left( \frac{p}{P_c P + P_{\bar{c}}(1-P)} \right) \right\}^2 \sigma_p^2 \\ &\approx \frac{P_{\bar{c}}^2}{\hat{p}^2} \sigma_p^2 \end{aligned}$$

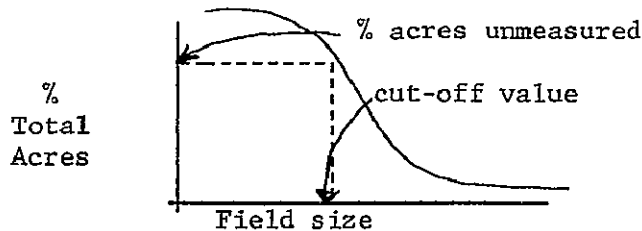


Finally

$$\text{Var}(\hat{A}'_M/A_T) \cong \left(\frac{P_i}{P}\right)^2 \sigma_P^2 \quad (33)$$

#### P.5 SENSOR CUTOFF

When the size of the fields become very small, then it becomes difficult and even impossible to determine the size. Assume that the sensor cutoff can be determined as the smallest field that can be measured with the particular sensor (MSS-TM) being used.



In the figure above it is seen that the cutoff size corresponds to some % of the fields not measured therefore, a correction factor may be applied to the measured fields (those above the cutoff sizes) to adjust for the bias created when the small fields were ignored. Let the corrected area of crop  $\Omega$  be given by

$$\hat{A}'_M = \hat{A}_M + f \hat{A}_M \quad (34)$$

where  $f$  is the correction factor determined from other sources of data and  $\hat{A}_M$  is the estimated area of sample crop  $\Omega$ . Then  $\hat{A}'_M$  is an unbiased measurement of sample crop size. The variance of this unbiased estimate is

$$\text{Var}(\hat{A}'_M) = \text{Var}((1 + f)\hat{A}_M) \quad (35)$$

Under suitable conditions the variance of a product of two random quantities (which we have here) can be obtained,

If  $g(x, y) = xy$  then

$$\sigma_g^2 = y^2 \sigma_x^2 + x^2 \sigma_y^2$$

Substituting

$$\frac{\sigma_{\hat{A}'_M}^2}{A_T^2} = \frac{\sigma_{\hat{A}_M}^2}{A_M^2} + \frac{\sigma_f^2}{(1+f)^2} \quad (36)$$

Dividing both sides by the square of the true area, which can be written as

$$(1+f)^2 A_M^2$$

$$\frac{\sigma_{\hat{A}'_M}^2}{A_T^2} = \frac{\sigma_{\hat{A}_M}^2}{A_M^2} + \frac{\sigma_f^2}{(1+f)^2} \quad (37)$$

In terms of % variance

$$\sigma_{\psi_{A'_M}}^2 = \sigma_{\psi_{A_M}}^2 + \frac{f^2 \sigma_f^2}{(1+f)^2} \quad (38)$$

#### P.6 COMBINING THE ERRORS

The discussion to this point has centered on the errors in the estimate of the acreage of the sample crop. These errors must be combined and propagated to the entire crop whether it be a local mission or a global one. The target region is presumably divided into strata and within each of the strata it is assumed for sampling purposes that the density of crop  $\Omega$  is constant. That is, for each strata, the acreage of crop  $\Omega$  can be computed as

$$\hat{p}_i A_{st_i}$$

where  $\hat{p}_i$  is the density of the crop as determined by the measurement process and this quantity is influenced by all five sources of error.

The density  $\hat{p}_i$  is estimated as the ratio of the acreage of crop to the total sample acreage, i.e.

$$\hat{p}_i = \frac{\hat{A}_{Mi}}{A_{\text{sample } i}} \quad (39)$$

The areas of the samples are known a-priori so that these areas are not random variables whereas the estimated areas  $\hat{A}_{Mi}$  are in error. These areas,  $\hat{A}_{Mi}$ , are those that have been discussed heretofore. If the estimates of  $\hat{A}_{Mi}$  were correct

and contained no measurement error then only the sampling error would be considered. The total acreage of a given crop is computed as

$$A_{TOTAL} = \sum_{i=1}^{N_{st}} \hat{p}_i A_{sti} \quad (40)$$

where  $N_{st}$  is the number of strata and  $A_{sti}$  is the area of the  $i$ th strata. The variance of the estimate of the total area can be obtained by applying the variance operator to the previous equation.

$$\text{Var}(\hat{A}_{TOTAL}) = \sum_{i=1}^{N_{st}} \text{Var}(\hat{p}_i) A_{sti}^2 \quad (41)$$

The variance of  $\hat{p}_i$  is in turn given by

$$\text{Var}(\hat{p}_i) = \frac{1}{A_{SAMPLE\ i}^2} \text{Var}(\hat{A}_{Mi}) \quad (42)$$

Therefore

$$\text{Var}(\hat{A}_{TOTAL}) = \sum_{i=1}^{N_{st}} \frac{A_{sti}^2}{A_{SAMPLE\ i}^2} \text{Var}(\hat{A}_{Mi}) \quad (43)$$

But the variance of  $\hat{A}_{Mi}$  for each strata is proportional to the area<sup>2</sup> as given by the expressions in the previous section.

$$\text{Var}(\hat{A}_{TOTAL}) = \sum_{i=1}^{N_{st}} A_{sti}^2 \frac{\hat{A}_{Mi}}{A_{SAMPLE\ i}^2} \sigma_{\psi_{AMi}}^2 \quad (44)$$

where  $\sigma_{\psi_{AMi}}^2$  is as before the % variance. Furthermore,

$$\hat{p}_i^2 = \frac{\hat{A}_{Mi}}{A_{SAMPLE\ i}^2}$$

So:

$$\text{Var}(\hat{A}_{TOTAL}) = \sum_{i=1}^{N_{st}} \hat{p}_i A_{sti}^2 \sigma_{\psi_{AMi}}^2 \quad (45)$$

Interpreting  $\hat{P}_i A_{sti}$  as the acreage of crop  $\alpha$  in strata  $i$ , then the per-strata variance can be written

$$\sigma_{sti}^2 = \hat{A}_{sti} \sigma_{\psi_{st}}^2$$

where  $\sigma_{\psi_{st}}^2$  is the % variance in strata  $i$  and  $\hat{A}_{sti}$  is the estimated acreage of crop  $\alpha$  in strata  $i$ .

For purposes of analysis, assume that all strata are equal area then the variance of the total crop can be written (in %).

$$\sigma_{\psi_{total}}^2 = \frac{1}{N_{st}} \sum_{i=1}^{N_{st}} \sigma_{\psi_{sti}}^2 \quad (46)$$

which demonstrates that the relative variance diminished as one over the number of fields measured.

The total area is as we mentioned a biased estimator; therefore, it must be corrected for classification and cut-off bias. The unbiased total area is then written as (within each strata)

$$\hat{A}_{Mi} = (1 + f_i) \left( \frac{\hat{P}_i}{P_i} \right) \hat{A}_{Mi}$$

that is; each estimate within the strata is computed and then the total summed. The sampling error must be added to this error to get the total error. If the quantities involved are not functions of the strata or correction terms can be found for the entire region (target area) then the corrections can be made after summing the areas within the strata.

**APPENDIX Q**  
**REPORT ON: TERSSE OPERATIONAL SYSTEM STUDY (TOSS) REVIEW**

## APPENDIX Q

REPORT ON: TERSSE OPERATIONAL SYSTEM STUDY (TOSS) REVIEW

Following the final TOSS briefing at NASA Headquarters in September 1975, a review of the study was conducted with several groups and individuals recognized to be knowledgeable of agricultural remote sensing. The result of the review was a report by the Earth Resources Program Office (ERPO) to NASA Headquarters (code ER) in October 1975. This appendix presents excerpts from that report.

The ERPO report itself had two Appendices which are not included as part of these excerpts as follows:

Appendix A, Letter from W. Stoney to ERPO requesting the review;

Appendix B, the attendees and their written comments from the review.

REPORT

TERSSE OPERATIONAL SYSTEM STUDY (TOSS) REVIEW

EARTH RESOURCES PROGRAM OFFICE  
JOHNSON SPACE CENTER  
DECEMBER 1975

## Introduction and Background

The purpose of this report is to document the results of a series of review meetings of the TERSSE Operational System Study (TOSS). The Study, initiated in April 1975, had as its objective the quantification of benefits to be obtained from improvement in accuracy of a Global Wheat Acreage estimate utilizing thematic mapper data and comparison with MSS scanner data in an equivalent system. Three questions were addressed.

- What is the economic benefit of a thematic mapper-based operational system?
- What does the system look like?
- How can system design be based on economic criteria?

Results of the Study were required to be available in time (September 1975) for possible use in the justification of the FY77 new start proposal for development of the thematic mapper.

The Study Team was composed of General Electric personnel, who had participated in the earlier Total Earth Resources System in the Shuttle Era (TERSSE) Study, and ECON, Inc., personnel who had conducted studies of economic benefits of remote sensing. It was stipulated that the Study effort should limit contact with LACIE personnel so as to minimize impact on that Project.

The final review was held at NASA Headquarters on September 18. As a result, it was requested (Appendix A) that a thorough review of the Study be conducted with both NASA in-house and outside people knowledgeable of agricultural remote sensing. Subsequently, a series of review meetings was held to obtain comments on and critiques of the Study. Reviewing groups included:

Purdue University (LARS)	September 30
ERIM	October 1/2
Dr. Roger Holmes (LACIE Advisory Group)	October 3
USDA (Washington, D. C. )	October 8
JSC-EOD/LACIE	October 10



Meeting attendee lists and follow-up written summaries of their critiques and comments are contained in Appendix B. This report will attempt to correlate the reviewers' comments, identify the consensus (or divergence) of opinions, and summarize the conclusions of the reviews.

### Issues and Approach

The major issues which prompted the review were specified in a letter from Mr. Stoney/Headquarters to the Earth Resources Program Office on September 19 (Appendix A). Each review group (with the exception of USDA) was specifically requested to address the following:

1. The merits and usage of spatial domain classification algorithms (per-field type) vs. per-pixel algorithms.
2. The reduction of the cloud-cover problem through the use of "floating" samples.
3. The reduction of operator and ground truth requirements by the use of unsupervised clustering algorithms.

In addition, they were asked to comment on the Study's conclusion that one spacecraft would be adequate for the Global Crop Survey Mission and encouraged to critique other aspects as they saw fit.

Obviously, the reason these became issues is that they represent different approaches to accomplishing the Crop Survey Mission than are currently accepted or underway, i.e., in LACIE. The crux of the matter is whether they are reasonable and viable options to be considered for an operational system. The basic techniques proposed have not been proven at this time and reviewer opinions varied as to what is reasonable and what is not. The techniques suggested in the Study are projections, in the opinion of the Study team, of what technology could be "reasonably" implemented in the early 1980's. As such, they are subjective.

Two questions arise regarding the proposed techniques: the technical merit of the approaches themselves and the practical considerations of implementing them.

The approach taken for the review process was to:

- State the purpose of the meeting and the specific issues
- Present the final review material in detail
- Discuss Study details and questions raised by the group
- Orally summarize the comments and results of the meeting
- Request written summaries of the groups' opinions, conclusions and comments

The following sections will individually address the above issues and others raised during the review.

#### Per-Field vs. Per-Pixel Classification

The TOS Study recommended utilization of a per-field type classifier which uses the data's spatial information to aid classification. The consensus of the reviewers' comments was that from a technical standpoint such classifiers are at least as good and probably superior to classifiers using only spectral information. However, with regard to the current state-of-the-art, various questions were raised and opinions expressed as to the reasonableness of implementation by the early 1980's.

Purdue cited several studies and publications, some very recent, and stated ". . . in our judgment, the end result of these studies, namely the predicted accuracy improvement, is not at all unreasonable and is the best projection we know of. . .", "accuracy improvement . . . [is due in part to] the basic advantage of per-field classification over per-pixel classification. . ." "There is, in our judgment, adequate evidence on the basis of both theory and of preliminary experimentation to suggest that by 1980 a per-field scheme can be ready for operational use."

ERIM believes ". . . the classification accuracies attributed to the TM and MSS [by TOSS] are too optimistic. . ." Regarding per-field vs. per-pixel, per se, they state, "Assuming that fields can be found, located accurately, and dimensions accurately portrayed, the per-field classifier should be superior to per-point. But finding field edges is a problem, and the contrast assumption in TOSS [10% of full scale] may be optimistic."

Dr. Holmes felt that "The review was less convincing on the ability to develop extractive data processing throughputs of the magnitude required. . . particularly on the basis of per-field classification." He pointed out that "labeling errors" must be considered, i.e., errors in labeling the fields once defined and that results of per-field classification to date indicate that improvement is a function of resolution. He states, "The real question to be asked is how much more time it takes to find boundaries and is the possible improvement using spatial correlation worth it?"

Although the LACIE group felt that per-field classification appeared to offer some advantages over per-pixel techniques, they questioned whether a sufficient level of effort would be dedicated to development of per-field classifiers, given today's state-of-the-art, for one to be ready for implementation in five years. They also noted that no specific classifier algorithm was proposed by TOSS and that with unknown performance and unknown interactions the conclusions regarding accuracy could change significantly.

They felt that the relationship between per-field classification accuracies and accuracies of proportion estimates for a given region need to be examined in order to evaluate the per-field approach.

In conclusion, it appears that per-field classifiers may offer improved accuracy vs. per-pixel classifiers, but that the operational technology does not exist today. Some reviewers, notably Purdue, felt that it is reasonable to expect that they can be developed by 1980. The costs involved with such development need to be examined as well as the associated operating costs as compared to per-pixel classifiers.

#### Cloud Cover Problem and "Floating" Samples

There was general agreement that a "floating" sample scheme was a technically viable means to reduce cloud cover problems; although ERIM stated, "There is some concern in our minds about the adequacy of current cloud cover statistics to answer the floating sample question with a high degree of confidence." Purdue felt, "Based on these experiences [Corn Blight Watch and Great Lakes Watershed Land Use Mapping Project], it is our judgment that the floating sample plan is a practical concept. We see no reason why it cannot be reduced to practice prior to 1980."

At issue is not the question of whether using floating samples increases the probability of avoiding clouds. Rather, the real issues here are: (1) the degree to which ground truth requirements may increase, and (2) the degree to which use of multitemporal analysis is precluded.

ERIM felt, "Reduction of cloud cover problem through floating samples will also require greater amounts of ground information, since all potential samples must be ground truthed." Ground truth information is used to either train the classifier or label unsupervised clusters. In a global survey, ground truth may not be available for some areas.

LACIE commented that multitemporal data is critical to recognition of wheat due to confusion crops at certain times of the year. Thus, they feel that the "floating" sample concept and the resultant one-satellite conclusion are suspect.

The TOSS concept envisioned utilization of multipass data, to the extent that it is available to assist in cluster classification. (Machine processing of multipass data in the multichannel sense, however, was excluded.) TOSS proposed the use of equivalent data samples where multitemporal data of the same sample sites is not available, due to clouds, in order to maintain a sufficient number of samples. However, the conclusion that one spacecraft is adequate is based on a one-sigma confidence (66 out of 100 years) of obtaining sufficient samples and it now appears that a higher confidence level would be desired in an operational system.

In light of some reviewers' opinion that multitemporal analysis (in the multichannel sense) will be necessary, one possibility would be to use floating samples to augment a basically multitemporal approach. In such a case, multitemporal analysis is used where multirate data is available and floating (non multitemporal) samples where there is insufficient cloud free data. This approach has not been analyzed in TOSS, and is suggested only as an alternative to an exclusively multitemporal approach.

In summary, the concensus of opinion of the reviewers was that more than one satellite was desirable and would probably prove justifiable. The "floating" sampling scheme appears to be a viable approach to provide valuable information in support of a classification approach based primarily on temporal information.

### Unsupervised Clustering

The TOSS approach to ground data processing proposes the use of unsupervised clustering of fields as a prelude to classification in contrast to the more conventional method of classifier training and supervised classification. As such, it is a method to accommodate limited ground truth (and reduce reliance upon it) rather than reduce operator interaction.

At issue is the trade-off between ground truth and operator interaction. The reviewers' opinions varied considerably. LACIE stated, "In our opinion, this low error rate [2% labeling error in the U.S. for unsupervised clusters] will require a comparison of the unsupervised classes with ground-acquired identification. In the U.S. [and the rest of the world] this will require a large amount of ground truth." However, they concluded that they "... feel [that] the unsupervised classification should be used as a tool to minimize the time and amount of human interaction in supervised classification rather than to try to conduct a program totally with unsupervised classification."

ERIM opined, "Reduction of operator and ground truth requirements by use of unsupervised techniques probably will be minimal. Operator[s] will have to decide what clusters represent wheat and will require probably about the same time and level of ground information to do that as to pick training data."

Dr. Holmes' comments focused on two aspects of extractive data processing; the time and machine size required to do the algorithmic process. He stated, "LACIE experience at the present time would seem to bear out the impression that the AI procedures can affect system performance in a critical way." He further stated, "The work of an AI and his interaction with system performance can be a very strong function of whether he really knows something about a sample of the entire segment or whether he is really guessing, no matter how educated a guess." Dr. Holmes was concerned throughout his review with the problems expected in the operational implementation of the extractive processing function. His major concerns were with the large amount of data to be processed in a global survey and the operator (AI) induced errors when ground truth was limited or lacking.

The Purdue group's comments seem to best summarize and validate the TOSS concept. They restated the issue and noted, "It has been found repeatedly that operator involvement can be traded off against ground truth requirements. That is to say, the effect of limited ground truth availability can be decreased by a greater operator involvement and one of the key tools for doing so is unsupervised classification (clustering)." Their elaboration of this is worth noting:

"In a number of cases, with which we have dealt, LANDSAT data has been classified into useful classes without the availability of any observations from the ground. This can generally be accomplished by increasing the training level and experience of the operator-analyst in two areas. These are

(1) his understanding of the geography of the area, that is, the geology, soils, land use, meteorology, and cultivation practices, etc., present in the area and (2) the inter-relationship of spectral response to these factors. Thus, while the degree of interaction in terms of number of hours per scene analyzed may not increase, the type of interaction between the operator-analyst and the data does change and in such a way as to replace the lack of specific ground observations at the time of data collection with an ability to derive this information from past experience and from current spectral observations. .

They then concluded that "Based on all of our experience over the past ten years, it is our strongly held belief that the human with his higher intelligence has an important role to play in the machine analysis of data, that it will be more cost effective if he is encouraged to play this role, and that system performance in any given circumstance will be improved by this participation. The development of algorithms such as clustering has been and should continue to be based on this assumption."

In summary, the issue as stated, i.e., the ability of unsupervised classification to reduce human interaction, has to be answered in the negative; no reduction in operator-analyst involvement is obtained, in fact an increase is required. However, the real issue is whether an increase in the quality of operator interaction can alleviate problems arising from limited ground observations. No consensus resulted from the reviews, but, an observation can be made. There is middle ground between the two points of view and an operational system may end up utilizing some aspects of each. The TOSS approach is to maximize machine processing and data sorting into clusters before human analysis and interactive classification. The other, more conventional approach, is to analyze the data and train the machine before classification. (Recent work has studied this approach by utilizing computer-generated recognition maps as an aid to the analyst in developing training data.) These are over simplifications of the two views, but it would seem appropriate in designing an operational system to attempt to optimize both man's and the machine's roles and stress their individual abilities. Also, all available information should be utilized in each step of the process.

The scope of TOSS did not permit a detailed design of the information extraction system to the level of selection of specific algorithms. This was noted by and was a major concern of Dr. Holmes. Some of this technology undoubtedly does not exist today. It would seem that development of techniques which can alleviate problems arising from lack of ground measurements (and likewise may reduce the need for extensive ground truth) is warranted. Unsupervised clustering may be one such technique.

### Number of Spacecraft

It was the consensus of the reviewers that one spacecraft was insufficient for the Global Crop Mission. LACIE comments were previously noted. Purdue commented, "While the specific analysis which led to the system's characteristics proposed appears sound and reasonable at this point and specifically while the analysis pointed to the need of only a single satellite, we find ourselves rather uncomfortable with this possibility. We hope that as other uses for such a satellite are considered, it will be possible to justify additional satellites operating at the same time, as we believe the impact on the application which was the subject of this study will benefit significantly from it also." ERIM felt, "... that more frequent satellite coverage is required. . ." and commented that their expectation of improved mensuration accuracies and benefits will be produced, in part, from "... temporal data acquisition probability with a 2-satellite system. . ." Also, as previously noted, the TOSS single-satellite conclusion was based, in part, on a one-sigma cloud cover confidence which in retrospect may be unrealistic for an operational system.

In summary, it is concluded that the number of satellites proposed be reevaluated and the appropriate changes made in the final report.

### Other Comments

There were numerous other issues and questions discussed during the several reviews. No attempt will be made to mention them all, but a few deserve comment.

(a) LACIE pointed out that the use of 16 pixels as a limiting field size classification cut off would bias the accuracy results toward the TM if field sizes tended toward small values, that is, a disproportionately larger number would be excluded from MSS classification. They also questioned the use of square pixels and in fields of 26 acres (16 pixels) for the MSS stating that 1.1 acre/pixel is a more accepted value for the MSS pixel size. ERIM commented that the 16 IFOV cut off was not unreasonable and that they had no data to justify another figure. The issue arose from the use of the word pixel rather than IFOV. TOSS used an 80 meter IFOV figure which translates to 26 acre fields. Pixel should not have been used interchangeably with IFOV.

(b) Economic Model

All reviewers expressed considerable interest in the economic benefits aspect of the Study. Few, if any, had had previous exposure to ECON's work. Discussions were of various degrees of detail and lengths. Questions indicated that confusion existed as to the terminology and methodology of economic analyses. Several reviewers expressed a desire to delve more deeply into the subject than time permitted during the reviews. This type of analysis is not well understood by the reviewing groups, which undoubtedly led to a general feeling that the benefits portion of the Study was "soft".

All the groups also expressed opinions to the effect that the Study should have addressed the system costs as well as benefits. The feeling was that the Study was incomplete and that some of the system components would probably change if cost vs. performance tradeoffs were made.

(c) Sample Size

- Various comments were received regarding the number of samples proposed in the Study. Purdue commented that the data was only an order of magnitude greater than they handled during the Corn Blight Watch and saw no problem with the capability of technology to handle it in the 1980's. Dr. Holmes was quite skeptical that a system could or would be developed to handle the volume of called-for data. He felt more detailed analysis was required before an approach to implementation could be developed.

LACIE questioned the large number of sites in light of the sampling accuracies used in the analysis in comparison to those experienced in their work. They expressed an opinion that no number should be identified as it will ultimately be determined by the specific sampling plan selected for an operational system.

The numbers used in TOSS are representative and considered to be a reasonable upper bound for an operational multicrop survey system. As such, they reflect the conservative (worst case) approach of the Study.

(d) Signature Data Statistics

The TOSS analysis incorporates a computer simulator to determine the per-field classification accuracy. The crop signature data used to exercise the simulation was extracted from published CITARS crop data statistics. Inasmuch as CITARS was not intended as a wheat study, several reviewers expressed a discomfort as to the representativeness of the crop statistics used. During the review process, both LACIE and Purdue expressed the opinion that the TOSS credibility could be improved by using statistics derived from the LACIE experience. The use of other data statistics should be considered as part of any further TOSS-related effort.



## Conclusions

The review was a useful and successful exercise. The general opinion was expressed by the various groups visited that the Study was well done and meaningful. Several commented favorably on its scope and depth. Summaries of the comments regarding the issues addressed follow. They are attempts to represent the consensus of opinions of the overall review.

### Per-Field Classifier

As good as, and probably superior to, classifiers using only spectral information. Efforts are needed to ready for implementation.

### Cloud Cover and Floating Samples

A valid concept for augmenting multitemporal classification; however, a more thorough analysis of cloud cover statistics is required for complete evaluation.

### Unsupervised Clustering

May improve system efficiency, but it remains to be proven.

### Number of Spacecraft

More than one spacecraft probably required and justifiable.

This report has addressed the comments and opinions obtained during the review and focused on a few key issues. By way of summary, the following comments were selected from the reviewers' written remarks as to the overall opinion of TOSS:

#### PURDUE

". . . have done a very important and very significant piece of work and done it especially well, without exception, the persons here who heard your presentation, were very impressed by it."

". . . the end result of these studies, namely the predicted accuracy improvement, is not at all unreasonable and is the best projection we know of."

#### ERIM

"In summary, except for our feeling that more frequent satellite coverage is required, we support the general conclusions of this study, but strongly recommend that more supporting evidence for the assumptions and conclusions be pursued."

Dr. Holmes

"The review was most convincing on the extrapolation by 1980 of current technology on the system front end. . ." "The review was less convincing on the ability to develop extractive data processing throughputs of the magnitude required. . ."

LACIE

". . . our review of the approach utilized to arrive at the estimates (acreage estimation performance) quoted by TOSS, leads us to believe that the conclusions depend critically on some very questionable assumptions."

PURDUE (LARS) TOSS REVIEW

W. Lafayette, Indiana

September 30, 1975

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ERIM TOSS REVIEW

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LACIE TOSS REVIEW

Johnson Space Center

October 10, 1975

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USDA TOSS REVIEW

USDA South Building, Room 3109

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October 8, 1975

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